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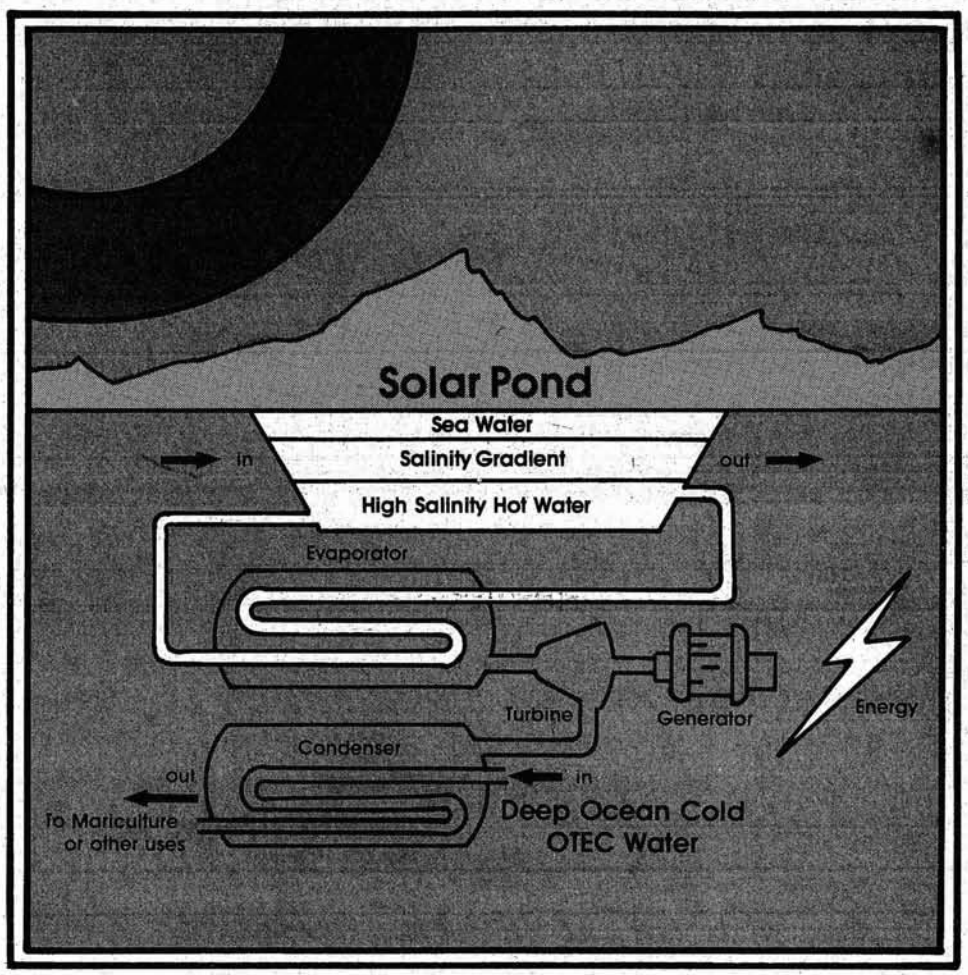
Engineering Design for Solar Pond OTEC (SPOTEC) Power Plants at Ke-ahole Point



For
Department of Planning and Economic Development
State of Hawaii

Prepared by SETS INC. Honolulu, Hawaii

Department of PLANNING
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March 27, 1984

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T. Yoshihara asked me to send the attached report (SPOTEC Design for NELH) prepared by SETS, Inc.

Gerald O. Lesperance

Attachment

FINAL REPORT

ENGINEERING PLANS FOR
A SOLAR POND OTEC (SPOTEC) POWER PLANT
AT KE-AHOLE POINT

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October 1983

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For:

DEPARTMENT OF PLANNING AND ECONOMIC DEVELOPMENT
State of Hawaii

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I. EXECUTIVE SUMMARY

The purpose of this report is to describe the conceptual design of a 15/30 KWe baseload/peak and a 300/600 KWe baseload/peak SPOTEC power plant and the engineering design of the 15/30 KWe plant. SPOTEC is the acronym for Solar Pond-Ocean Thermal Energy Conversion and represents the combining of solar salt-gradient pond and OTEC technologies. A solar salt-gradient pond and power plant facility is designed which could stand alone or could be combined with deep ocean cold water to increase efficiency of power generators. The designs are described principally in the drawings and specifications contained in separate packets. This report elaborates on the drawings, provides additional specifications, and gives some background and insight into why and how certain design choices were made. This report also presents options and trade-offs which can be used to scale the development project up or down in cost, schedule and scope.

It is suggested that the construction of the 15/30 KWe facility be carried out as the next phase of the project. To facilitate this, a description and proposal of how the project would be carried out for each major part (civil, mechanical, electrical, instrumental) including technical specifications, drawings, and bidding materials and instructions, are submitted as a separate package.

This design project was contracted to SETS, Inc. by the State of Hawaii Department of Planning and Economic Development after SETS, Inc. developed and presented the concept and technology. The project covered a period from 10/01/82 to 6/30/83 and involved SETS, Inc. personnel and several sub-contractors, including the Jet Propulsion Laboratory of Pasadena, California.

The result of this effort is a design which is very likely to succeed from a technical standpoint. All technical design objectives were met and no technical uncertainty is known which could prevent achieving at least the minimum level of performance specified.

A construction plan and schedule is presented which appears to be realistic and readily attainable given reasonable weather conditions, few labor or regulation problems and timely funding. The construction schedule could be stretched out to spread costs over a longer time period without significantly increasing the overall cost of the project (except for inflation). A firm such as SETS, Inc. with solar pond technical expertise must be involved in a major way with the facility construction to insure the design and plan is properly implimented

Several design options are presented for the 15/30 KWe SPOTEC plant. All options include an energy collection and storage pond, a brine production facility, plumbing, instrumentation, and energy conversion (thermal to electrical) equipment. The major options concern the size of the energy pond (0.64 acre and 1.2 acre at top of storage zone, which defines energy collection and storage area) and its effect on sizing of the brine production facility and other related parts. All options meet or exceed the required major design requirement of 30 KWe peak power and the informal request of 15 KWe average gross power output. These options were generated to give the contractor examples of how cost scales with size and to allow continuation of the development of SPOTEC under different budget scenarios.

The cost estimate for complete construction and initial warm-up of the facility, including management but not taxes is $682,669 for the minimum facility (0.64 acre storage zone top area) to produce 15 KWe average gross power and $848,376 for the larger facility (1.2-acre storage zone top area). This cost would be spread over a 18-24 month period.

The cost estimate is somewhat higher than rules of thumb would suggest. This is partly because this facility would be a first-of-its-kind in Hawaii and would be intended partly for research. Also the basalt rock at the Ke-ahole site is very expensive to excavate, requiring the pond to be built above ground using off-site material. This adds as much as $200,000 extra cost to the construction of the minimum facility. Subsequent similar facilities and larger facilities built in Hawaii and at the Ke-ahole site would have a significantly lower cost.

The construction of this first SPOTEC facility would have several favorable impacts on Hawaii, such as:

* Most of the construction funds would be spent in-State, with several man-years of jobs resulting.

* A new practical and appropriate alternate energy conversion system would be proven in Hawaii for use here.

* The State would enhance its reputation as a fore-sighted innovative developer of alternate energy conversion.

* This new technology would be transferred to in-State firms and personnel, creating a new high technology industry.

* The technology would form a new exportable, high-technology product and service.

* The technology is appropriate for many other Pacific islands and thus it could become a Hawaii contribution to its Pacific island neighbors.

* The project is very likely to be successful on a short (less than 2 years) time scale; only the exact operating efficiency is uncertain, not whether it will work or not.

* The facility would be a major research resource to attract future funding for development in areas such as solar ponds, OTEC, heat engines, and desalination.

* The facility does not "destroy" the OTEC cold water used and so it does not displace other users.

* A practical application of a larger follow-on facility exists in the Ke-ahole airport. The Department of Transportation could apply the experience gained in the first facility for its own power needs at Ke-ahole

and eventually at Honolulu and other airports.

II. INTRODUCTION

A. Statement of the Work

The general statement of work for this project is to prepare the conceptual and engineering design for a 30 KWe SPOTEC power plant and the conceptual design for a 300 KWe SPOTEC power plant. Solar Pond (SP) and Ocean Thermal Energy Conversion (OTEC) technology are to be combined into a hybrid system called SPOTEC for maximum efficiency. These plants are to be located at the Natural Energy Laboratory of Hawaii (NELH), Ke-ahole Point, Hawaii, and are to provide power for the NELH and the Ke-ahole Airport.

It is understood that the 30 KWe power output specified in the contract for this work for the smaller facility refers to peak power and that 15 KWe is the informal average gross power output (baseload) design target. The 300 KWe output specified for the larger plant is understood to be approximate average gross power output (baseload) and the peaking requirement is understood to be about 600 KWe. The 300/600 KWe values are determined by the approximate power usage expected for the Ke-ahole Airport in the near future. The 15/30 KWe values are determined by the desire to develop a first-of-its-kind facility in Hawaii which is of a scale to be technically significant and efficient and to provide some useable power to the NELH at the lowest initial cost.

The detailed scope of work is given here verbatim as stated in the D.P.E.D. contract to SETS, Inc.

1. <u>Scope of Services.</u> CONSULTANT shall perform and provide, in a satisfactory and proper manner as determined by DPED, the following services:

   a. Prepare a conceptual design of a complete 300-KW SPOTEC facility.

   b. Prepare an outline plan to design, construct and operate a complete 300-KW facility.

   c. Prepare a conceptual design of the first 30-KW module.

   d. Prepare an engineering design of the first 30-KW module, including

      (1) site selection
      (2) gathering of environmental data
      (3) pond design
      (4) design of a power conversion facility
      (5) design of an instrument and monitoring system
      (6) design of a pond maintenance facility
      (7) design of support facilities, including warehouse, operators' center, roads and utilities, and visitor facilities
      (8) provision of proper systems integration, including interfaces, compatibility of equipment and materials, and overall physical

plant layout on site
(9) provision of an operation and maintenance plan
(10) provision of a construction plan and cost estimates.

e. Calculate overall performance of the first module pond and power plant.

f. Prepare a power distribution plan.

g. Prepare a conceptual design of a salt production facility.

h. Prepare the engineering design for a salt production facility to include

(1) selection of site
(2) design for a passive facility
(3) design for an energy-enhanced facility
(4) design for a salt storage facility
(5) design for a brine delivery system
(6) preparation of an operations and maintenance plan
(7) preparation of performance calculations
(8) preparation of a construction plan and cost estimates.

i. Define salt purchase and delivery option and document.

j. Research environmental impacts and permitting procedures.

k. Prepare public information plan.

l. Provide DPED with progress reports every month, and 20 copies of the final report.

2. Time of Performance. Performance of services of CONSULTANT shall commence on October 1, 1982, and all the services required under this Agreement shall be completed by June 30, 1983, unless this Agreement is sooner terminated as hereinafter provided.

B. Method of Accomplishing the Work

The work was accomplished using a SETS, Inc. in-house team of engineers, scientists and others as well as several sub-contractors to provide specialized expertise.

Options for the two designs of the power plants were investigated: (1) a minimum facility and (2) a maximum facility. The characteristics of the associated solar ponds (which drive the remainder of the design) are:

15/30 KWe Facility

Item	Minimum	Maximum
Pond Surface Area	0.81 acres	1.31 acres
Energy Collection Area	0.64 acres	1.15 acres
Pond Bottom Area	0.50 acres	1.00 acres
Embankment Slope (interior)	2:1	1 1/2:1

300/600 KWe Facility

Item	Minimum	Maximum
Pond Surface Area	11.78 acres	22.65 acres
Energy Collection Area	10.88 acres	21.31 acres
Pond Bottom Area	10.00 acres	20.00 acres
Embankment Slope (interior)	2:1	1 1/2:1

The drawings were made for the maximum design but could easily be remade for the minimum design or something in-between if desired. No change in concept is required and many drawings would not change at all. Specifications and cost estimates are given for both options.

The Jet Propulsion Laboratory of the California Institute of Technology was a subcontractor to SETS, Inc. and was charged with providing technical advice particularly in the areas of pond gradient establishment and maintenance, hot brine extraction and return, pond surface washing, and pond liner evaluation. In addition JPL aided in reviewing the overall pond design and in the area of filtering and water treatment. SETS, Inc. personnel held monthly reviews of the JPL work progress during the period of the JPL subcontract (February 1 - June 30).

Other subcontractors were:

Kona Surveyors: site topographic maps.

Chester Jenkins: salt production methods.

Mr. Leo Fleming, CE.: platform elevations for power/evaporation pond; calculate required materials and quantities for pond construction.

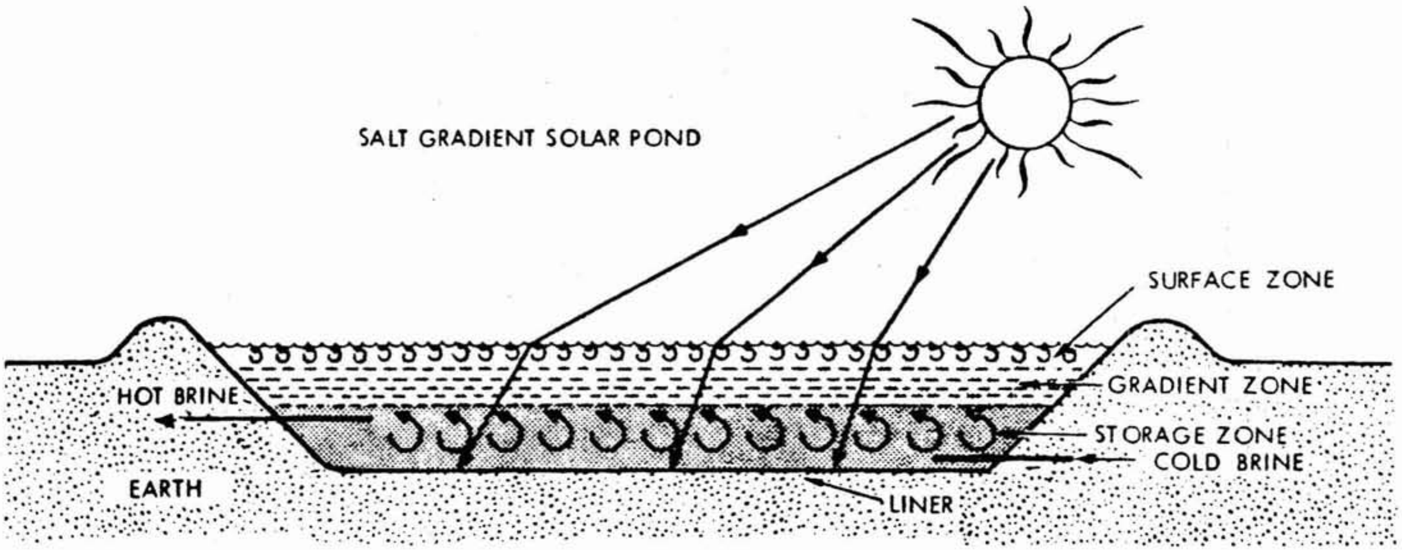
Wallace T. Oki, P.E.: electrical.

The SETS team held bi-weekly review meeting and met in smaller groups more often. There was considerable interaction to insure a collective absorption of the technology.

Monthly progress reports were prepared by SETS for the DPED contract monitor (Mr. Howard Pennington) and monthly in-person review meetings were held for DPED personnel (Mr. Pennington, Mr. G. Lesperance) at the SETS, Inc. office.

Figure II-1.

Salt Gradient Solar Pond



By mutual verbal agreement (at the June 1, DPED review meeting) between Mr. Pennington and Mr. Lesperance of DPED and Dr. McCord of SETS, Inc., the final report was not to be finally printed until it was reviewed by DPED, was to occur after the June 30 formal end of the work period.

The reviews were made and a written response was sent to SETS, Inc. from D.P.E.D. on July 19, 1983. The revisions requested were made and the final product produced on September 26.

C. Description of Salt-Gradient Solar Ponds

A solar pond is a body of water that converts solar energy into thermal energy (Figure II-1). Currently, research is being conducted to develop several classifications of ponds typically labeled "salt gradient," "saturated," "shallow" and "membrane." Among these classifications the salt-gradient pond has received the most attention because of its inherently large thermal storage capacity, potentially lowest cost and capability of coupling with electric power generation equipment.

In a normal body of water, a portion of the solar radiant energy penetrates into the sub-layers. As the radiant energy passes through successive layers, it is gradually absorbed and causes the water to warm. The warming decreases the density and the water rises, carrying with it the absorbed solar energy. At the surface the energy is lost to the atmosphere by radiation, evaporation, and convection. Thus, the body of the water remains cool.

In a salt gradient solar pond, density is made to increase with depth. This condition is achieved with a high salt concentration at the bottom and a low concentration at the surface. With a sufficiently high salt concentration or density, lower zone waters can absorb solar energy and yet remain denser than the waters immediately above. Convective currents are eliminated; therefore the lower zone waters remain in place and continue to absorb solar energy. Temperatures over 100 degrees C (212 degrees F) have been observed in the bottom zone of working solar ponds.

Salt gradient ponds are typically bodies of salt water, 2.5- to 5-m (8 ft. to 16 ft.) deep. The specific gravity of the bottom layer is close to 1.2, while the surface is maintained near 1.0. The ponds, depending on size and depth, are capable of storing tremendous amounts of thermal energy and, therefore, can supply energy on a continuous 24-hour/day, 365 dy/yr basis. In electric power generation applications, solar pond power plants can deliver base-load power with load factors of 0.8 to 0.9 or more, or they can be operated at high output levels to meet peak demands.

In practice a solar pond will have three distinct layers or zones: an upper convective layer, a middle non-convective layer, and a bottom storage layer. The upper convective layer, which has a very low uniform salt concentration, is 0.15-m to 0.3-m (6-inch to 12-inch) thick; it exists because of wind-induced mixing and diurnal effects of heating and cooling. The energy absorbed by the upper layer is lost; therefore, efforts must be taken to minimize its thickness.

The non-convective layer, also known as the gradient zone, is 1.0-m to 1.5-m (3 ft. to 5 ft.) deep with salt concentration increasing with the depth (from less than 8% at the top of 20% or higher at the bottom). This zone is the key to the successful operation of a solar pond. It allows radiant energy to penetrate to the lower zone and acts as an insulator between the bottom and upper layers, a function similar to the glazing layer of a flat plate collector.

The bottom, or storage, zone is convective with a uniform high salt concentration. This zone may be 1-m to 4-m (3 ft. to 13 ft.) deep, depending on the storage needs of a specific application.

The types of salt that can be used in a solar pond include sodium chloride, magnesium chloride, sodium carbonate, sodium sulfate and others. Natural sea-salt is acceptable. The basic requirement is high solubility and transparency and a solubility curve which does not decrease with increasing temperature.

During the normal operation of the pond, salt will gradually diffuse from the bottom to the surface layer. This action, although very slow, tends to degrade the salt gradient. In order to maintain the necessary salt gradient, the surface layer must be flushed with fresh or low salinity water from time to time. Meanwhile, high salinity brine must be injected into the bottom layer to make up the salt loss.

Figure II-2 is a schematic diagram of a solar pond power plant. The solar pond transforms solar energy into thermal energy, and a heat engine converts the thermal energy into shaft power that in turn drives a generator to produce an electricity output. Cold water for condensing the organic fluid may be taken from the upper convective zone of the pond or from any other convenient source of cool fresh, brackish or sea water.

The solar pond can collect and store as heat as much as about 20% of the incident sunlight. Conversion of this heat to electricity can be made at about 10% efficiency. Thus, the overall conversion from sunlight to electricity can be about 2%. For favorable tropical environments this means an acre (43,500 square ft. or about 4000 squared meters) can produce about 20 KW of electric power 24 hours a day, 365 days a year, or about 175,000 KW hours of electricity per year.

The solar pond is a source of firm (base or prime) power. That is, it can produce power day or night, during clear or cloudy weather. This is the case because the length of time it takes to change the temperature of the pond is very long. From start of pond operations it can take six months to one year to come to full operating temperature (about 95 degrees C or 200 degrees F). But it also takes that long or longer to cool down if no sunlight is available. Thus cloudy weather, for even weeks at a time, does not significantly affect the power production from a solar pond when it is in full operation.

D. History of Salt-Gradient Solar Pond Technology

The salt-gradient solar pond phenomenon was first reported by von Kalecsinsky in 1902 in connection with the Medve Lagoon in Transylvania. It was suggested by von Kalecsinsky, and later by R. Block in 1948, that artificial ponds be established after the natural salt-gradient lakes to harness solar energy for practical utilization. However, development of salt-gradient solar ponds did not take place until the last two decades when the pressure of escalating conventional fuel costs began to be felt. The mid-late 1970s saw

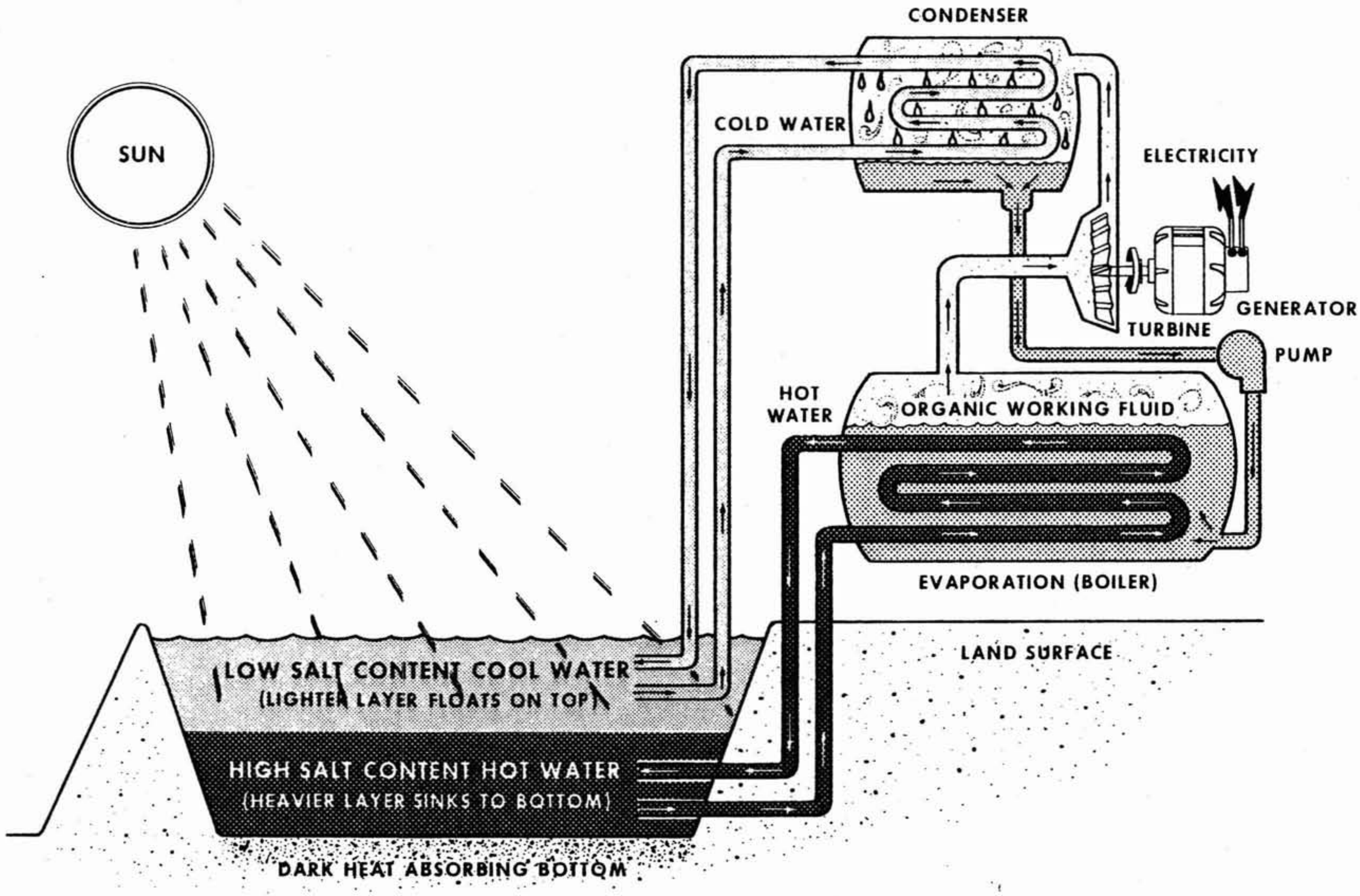


Figure II-2.

Solar pond generating concept

several experimental pond programs of modest scale launched in the United States, and some demonstration pond facilities operated in Israel. Much knowledge of solar pond behavior, and experience related to its operation and maintenance have been acquired through these efforts.

In 1960, Harry Tabor and his colleagues in Israel began to develop the serious application of the solar pond principle. Work was soon dropped because of low oil prices, but in 1973, when oil prices skyrocketed, the effort was renewed. Solar pond development activities have since been accelerated, both in Israel and the United States, as well as in other parts of the world. Ormat Turbines, Ltd., and the Israeli Government have produced several salt-gradient solar pond power plants (SPPP) on the Dead Sea which are still producing electricity. The first of these, built at Yavne in the early 1970's, has an area of 1250 square meters (0.3 acre) and produces 6 kilowatts of electricity. A larger, 7000-square-meter (1.75 acres) pond began operation in Ein Bokek in December 1979. It can produce 35 kilowatts continuously or a peak of 150 kilowatts. Then, a 40,000 square meter (10-acres) pond was constructed and filled and has now warmed up. Ormat and the government are now finishing a 250,000-square-meter (62.5 acres) demonstration pond at Beit Arava that is scheduled to begin producing 5 megawatts of electricity in September 1983. This is the first of a series of SPPPs around the Dead Sea that the Israelis hope will be producing somed 2000 megawatts of electricity by the year 2000. This will be a significant amount in a county that now has only 2700 megawatts of capacity.

In Australia, a 2000 square meter (0.5 acre) pond at Alice Springs has been completed and heated up. Power was first produced in late 1982 and power conversion equipment modifications are now underway. Additional ponds are planned by the National Research, Development, and Demonstration Council as well as several regional governments.

Several ponds with specific applications are in operation in the United States. For example, in Miamisburg, Ohio, a 2020 square meter (0.5 acre) solar pond was constructed in 1977 to provide heat for an outdoor swimming pool in the summer and an adjacent recreational building from October to December. In Wooster, Ohio, a 156 square meter (1700 square ft.) solar pond was constructed in 1975 to heat a greenhouse in the winter. Four research ponds are also in operation in this country. The research pond at the University of New Mexico has a surface area of 175 square meter (1906 square ft.) and the pond at Argonne National Laboratory, in Illinois, is about 1000 square meter (0.25 acre). Two other research ponds are in Columbus, Ohio.

A 4000 square meter (1-acre) pond construction has been completed by the TVA (Tennessee Valley Authority) at Chattanooga, Tennessee. At last report it was heating up.

Work has begun on a demonstration salt-gradient solar pond system at Los Banos in California's Central Valley. This system, being built in conjunction with a reverse osmosis desalting facility to test the feasibility of reclaiming saline agricultural drainage water, will consist of two half-acre solar ponds with a Rankine-cycle energy conversion unit. A small separate reverse osmosis desalting plant will be operated by the Rankine unit to demonstrate the system's possibilities for providing power for desalting on a large scale.

Several other design experiments have also been undertaken elsewhere in the United States. They include the Truscott Brine Lake in Texas, and the Gray Mountain pond in Arizona.

In late 1979, the United States initiated the Salton Sea experiment, with the purpose of constructing its first 1,000,000 square meter (250 acres) 5-MWe solar pond water plant in the Imperial Valley of Southern California. The first phase of the activity, the feasibility study, has been successfully completed, and the engineering design was begun. It is noteworthy that, as a reflection of interest from diverse sectors, the project was co-funded by the U.S. Department of Energy, the California Energy Commission, and the Southern California Edison Company, and was managed by the Jet Propulsion Laboratory. Sponsor collaborative arrangements were recently re-assessed and a different arrangement involving outside investment capital is not completed.

This project for Ke-ahole, Hawaii, is a major increment in this development history in that it could be the first solar pond in the United States to produce electricity and the first facility in the world to combine with OTEC and use deep-ocean cold water.

E. Status of Salt-Gradient Solar Pond Technology

Preceded by the Israeli studies in the early 1960s, research and development efforts undertaken during the last seven or eight years, principally in the United States and Israel, have advanced the solar pond technology to the point where it can be referred to as a proven technology. Although much has been learned, efficiency improvements are still important. Nielsen (1980), Lin (1982), and Tabor (1981) review the state of the technology in detail, and cite a large number of publications which can be consulted for further information. Only a brief overview of the pond technology is provided here.

One or two dozen solar ponds have been constructed and operated around the world (mostly in the United States and Israel). Construction of small ponds (excavation, diking, lining, filling, installing piping and instrumentation, etc.) has proven to be straightforward. Several larger ponds are either under construction or design, including Israel's 5-MWe plant and the Salton Sea 5-MWe experimental pond. In-lake diking and high salinity brine production from low-salinity water may be improved by innovative approaches, but can be accomplished with standard techniques.

Pond storage temperatures experienced varies from a low of about 30 degrees C in winter (Ohio) to a high of 109 degrees C in summer (New Mexico) (Weeks and Bryant, 1981). Boiling can be achieved in high-insolation locations and can be avoided by scheduled heat extraction. Heat extraction both by in-pond and out-of-pond heat exchangers have been successfully performed, the latter means being preferred from experience.

A variety of thermal applications have been successfully demonstrated, including pool heating, grain drying, process water heating, space and greenhouse heating. The Yavne and Ein Bokek ponds have established the feasibility of peaking and baseload electric power generation. Larger scale applications remain to be demonstrated, but their success is anticipated. Thermal efficiency on the order of 10 to 20 percent, and thermal-to-electrical conversion efficiency of 8 to 10 percent, have been established yielding overall efficiencies in the range of 1-2% solar to electrical.

The salt-gradient zone has been found to be generally stable. No dramatic failure of the gradient has occurred. Convective sublayers of a few centimeters thick have been observed within the gradient zone and simple methods have been established to rapidly correct them. Boiling was found to cause gradient instability and large amounts of heat loss, but it did not destroy the gradient. Divers performing maintenance/repair and boats rowed across the surface did not disturb the gradient zone in any longterm noticeable way. Knowledge is being gained of the mechanisms and physical factors that control gradient boundary migration and its thermal and hydrodynamic behavior, although a complete understanding has not been achieved.

Salt diffusion from the storage to the surface zone can be countered by reinjecting salts or heavy brine into the storage zone and flushing the surface with fresh or low-salinity water. This has become a standard practice for every operating pond, and the effort involved is minimal.

High winds have not produced damage to the ponds. Wave-suppressing networks installed on pond surfaces have been effective in preserving the pond's integrity even during gusts in excess of 120 km/hr according to Israel reports. No record exists of any pond damage due to rain or hail storms. Two or three months' snow and ice coverage on the pond surface do not drastically degrade a pond's performance. Ponds located in the low-insolation northern states of the United States are capable of sustaining a storage temperature of about 30 degrees C during the winter months. Fallen leaves, dust and debris can be easily removed from the pond by surface flushing or swimming pool type cleaning techniques. Algae growth can be prevented by applying weak solutions of copper sulphate or chlorine.

Reaction between hot brine and pond bottom mud in an unlined pond could potentially lead to gas bubbling or rising sediment. Turbidity and coloration can reduce solar transmittance into the storage zone, but proper water treatment including settling, filtering and carbon treatment has been found to be effective in removing the suspended particulates and organic matters that cause these problems. Corrosion has damaged the heat exchangers of the Miamisburg pond, because of the improper metals used, but has not done any damage to other pond installations. Liner breakage has occurred to at least two ponds; causes for breakage were determined and repairs performed. The usual cause of liner damage is slumping of the pond berm material and stressing of the liner. Salt leakage accompanying liner breakage was not found to severely contaminate the environment. Evaporation from open pond surfaces resulting in water losses can pose some constraints on pond applications, especially in arid regions where water (fresh and sea) is in short supply. Evaporation suppressants which can be applied to pond surfaces are being investigated. Earthquakes and tornados have not been experienced by any existing ponds. They may conceivably damage ponds, but special design considerations and repairs can be exercised as they are with other types of structures or power plants. No ponds have been a visual, safety or any other type of environmental hazard.

In short, what has been learned and experienced on solar ponds has been positive. The capability of ponds to collect and store solar energy has been repeatedly confirmed, even in areas where insolation is relatively low. They have been proved to viable producers of usable thermal and electrical energy. This does not mean, however, that all the problems have been solved.

Research and development are still needed in a number of important areas. These include surface zone phenomena, optical performance, gradient stability, heat extraction rate and methods, corrosion, water treatment techniques, mud-brine reaction, evaporation suppression, hydrodynamic effects of scaling up pond sizes, system optimization, brine concentration techniques, dike construction schemes, pond sealing techniques, and improved operation and maintenance procedures. These investigations will further our understanding of solar ponds, improve their design and construction, enhance their performance, and reduce the costs of thermal and electrical energies that are derived from them.

F. Uses of Salt-Gradient Solar Ponds

Salt-gradient solar ponds have many potential applications which include: residential and commercial space and water heating, agricultural and industrial process heat, electric power generation, desalination. A salt-gradient solar pond can provide relatively low-cost solar energy collection and long-term storage of low-temperature heat.

1. Electricity

One of the most attractive applications of solar ponds is in the area of electric power generation. A solar pond (SPPP) can produce baseload and peaking electric power to match most load demands. There are options which other solar energy systems can achieve only with large investments in battery storage. However, the efficiency of the process is low and commercial electric power generation will be confined to those areas or sites where the pond ingredients (such as sun and salt) occur naturally, or to sites in remote areas.

The efficiencies of the process are important to the economics of the system and greatly depend upon the hot brine and cooling water temperatures. At temperatures of 92 degrees C in the storage zone and 28 degrees C in the cooling water, the efficiency of converting solar pond thermal energy to electric energy is about ten percent (approximately 67 percent of the Carnot theoretical maximum). This conversion efficiency, coupled with a pond solar energy collection efficiency of 20 percent means that the total system efficiency from solar-in to electricity-out can be about two percent.

Electric energy in remote or island locations is much more expensive than energy from a large utility grid. Solar pond power plants could become an inexpensive option for remote applications. In Hawaii, for example, electric energy cost 12 to 15 cents/KWH, and in other island centers the actual cost of producing electricity is in the range of 25 to 50 cents/KWH or more.

Currently cost estimates for SPPP construction ranges from about $4,000 to $25,000 per installed kilowatt electric base power for large and small first-of-a-kind plants, respectively. This compares with $2,000 to $4,000/KWe for new oil-fired generation plants. The operating cost for SPPPs are estimated at 2 to 10 cents per KWH, well below oil-fired plants.

Economic studies show SPPPs can be more economical over their life time than diesel power plants, especially for small plants in isolated sites.

The SPPP is a source of firm or base power, i.e. it produces power 24 hours a day, 365 days a year regardless of weather. This is the most desirable kind of power.

2. Desalination

It is possible to use a solar pond to supply thermal, mechanical or electrical energy to a desalination process. It is also possible to use the waste brine effluent from the desalination plant as feed stock to evaporation ponds for production of concentrated brine for maintenance of the solar pond or for initial filling of additional solar ponds at the nearby site. Use of waste brine may reduce or eliminate desalination plant effluent disposal costs and may reduce solar pond costs through reduction in evaporation pond area.

The thermal, mechanical and electrical requirements for the various desalination processes may be satisfied by a solar pond alone, a solar pond in conjunction with another energy source, or another energy source alone.

The thermal energy source must be located on-site due to energy transport loss considerations, whereas a solar pond or other source of electrical energy may be located either on-site or off-site with power fed through the local power grid.

3. Crop Drying

One relevant use for a salt-gradient solar pond in the Pacific Islands is for crop drying. The temperature of the thermal energy requirements for crop drying and the need for continuous, stable energy are both consistent with solar pond characteristics. In addition, the application will be rather simple and direct. Its main requirement is a hot brine transport system and a heat exchanger to transfer the heat from the hot brine to the drying medium, usually air.

4. Irrigation Pumping

Irrigation of crops could also be a significant application of SPPPs in the Pacific Islands where rains are not sufficient or are seasonal and where sufficient fresh water is available. Pumps could be run using electricity in a dependable, low cost way to irrigate without fear of interrupted fuel supply.

5. Heating and Cooling Buildings

Heat can be used for many purposes. One important area is in heating and cooling buildings. The stored heat in a solar pond can and is used directly to heat buildings, greenhouses and swimming pools in cold climates. The heat can also be used for airconditioning and refrigeration using heat engines.

G. Potential Symbiotic Activities

1. OTEC

An interesting and potentially very important opportunity exists for advancing the technology and achieving signific savings by combining solar pond technology with OTEC technology (Ocean Thermal Energy Conversion). The cold, deep ocean water available from an OTEC pipe, such as exists at Ke-ahole Point in Hawaii, could be used instead of the warmer solar pond surface water to condense the working fluid in the electrical generator turbine. The efficiency of the overall energy conversion would then be increased by 20 percent over that for the normal solar pond because of the larger working temperature difference. Looking at it another way, the OTEC is made 460 percent more efficient by using solar pond hot water rather than the cooler ocean surface water in the OTEC turbines. SETS, Inc. has coined the acronym SPOTEC for the Solar Pond/Ocean Thermal Energy Conversion hybrid.

2. Mariculture

The potential for combining mariculture activities with solar ponds exists and SETS, Inc. is developing plans for solar ponds which take advantage of this opportunity. A certain amount of fresh sea water may be pumped to wash the surface of the salt pond, to operate the cold side of the generator turbine heat exchanger and to produce salt for brine replacement. In addition it is desirable that nutrients be stripped from this water. For very little extra cost this moving sea water could accommodate growth of certain commercially important mariculture products while cleansing the water. Power for pumping the water is provided by the pond itself.

When OTEC cold water is used, mariculture may become even more practical for the deep ocean nutrient-rich water would be used.

III. Site and Description

A. Location and Geographic Setting

The site given by the contractor for the initial SPOTEC facility is on the largest of the Hawaiian Islands, the Island of Hawaii (locally called the Big Island) at the Natural Energy Laboratory of Hawaii (NELH) (Figure III-1). NELH lies at the western end of Ke-ahole Point in the North Kona district. Ke-ahole Point lies seven miles north of the principal Kona coast town of Kailua (latitude 19 degrees, 44', N, longitude, 156 degrees, 03', W). The Ke-ahole airport is east of and adjacent to the NELH area.

The Big Island of Hawaii is the largest island and county in the Hawaiian islands with an area of 4,038 square miles. It was formed by five volcanoes, two of which are quite active. Principal industries on the Big Island are sugarcane growing and milling, tourism, diversified agriculture and cattle ranching. Diversified agriculture includes macadamia nuts, anthuriums, orchids, coffee and other tropical flowers, fruits, vegetables and foliage.

The resident population of Hawaii County is approximately 94,000. The county seat and main population center is Hilo on the eastern side of the island. Ethnic makeup of the island shows no ethnic majority: Japanese 23.1%; Caucasian 21.4%, Filipino 11.0%; Hawaiian and part-Hawaiian 33.2%; with other minority groups making up the remainder. The North Kona district is experiencing a rapid population growth attendent with its growth of tourism related facilities and job opportunities.

The County of Hawaii serves as an example of alternate energy research, production and utilization. Over 40% of the electricity used on the Big Island is fueled biomass (bagasse) with hydroelectric and geothermal also supplying energy to the grid. The county and state are quite supportive of expanding alternate energy production and decreasing the dependence on fossil fuels.

The specific site for the initial SPOTEC power plant facility at the NELH facility is shown on the plate Map (Figure III-2). This site is located east of the NELH compound on the ocean-side of the access road at an elevation of between 12 and 18 feet above mean sea level. The site has been formally assigned to the project, at SETS, Inc. request, by the NELH Board of Directors (see letter on following page).

B. Criteria for Site Selection

In general, the criteria for selection of a solar pond site includes the following:

Land

- availability and cost of land
- government plans, policies and zoning regarding land use and alternate energy production and use
- well drained, dry soil for good thermal insulation
- flat land to minimize earth-moving requirements

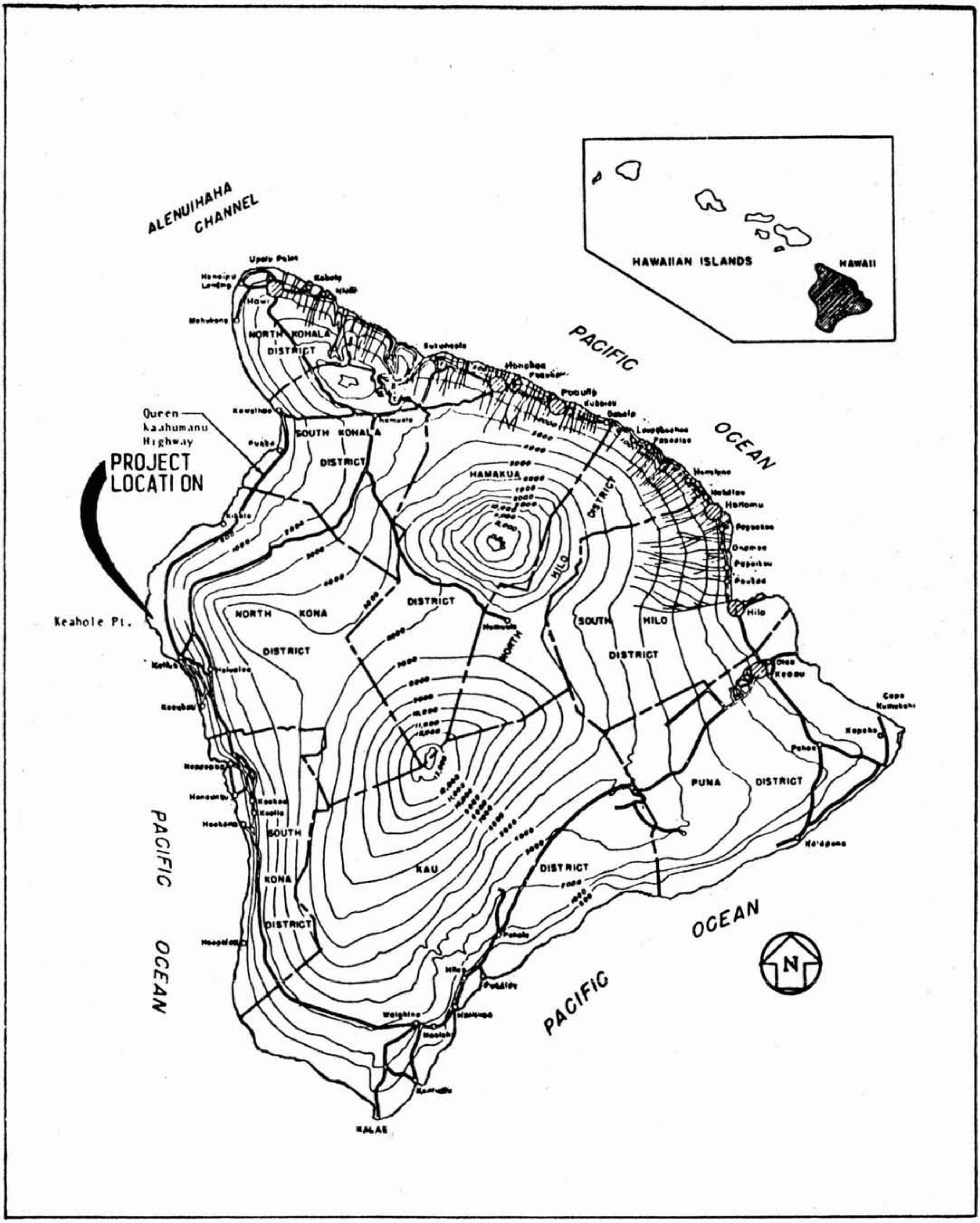


Figure III-1.

SPOTEC Power Plant Facility Project Location

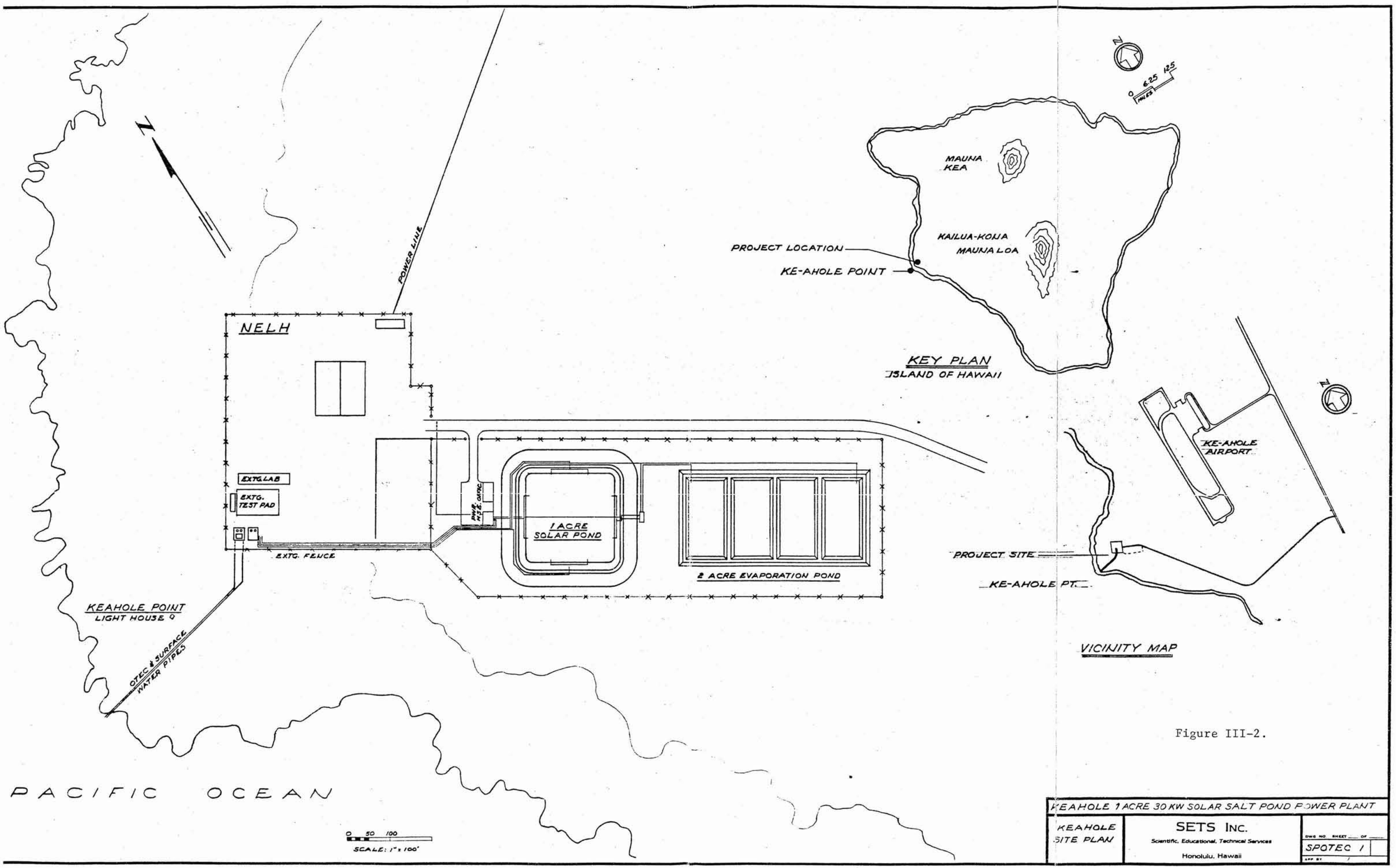

NELH
POWER LINE
EXTG. LAB
EXTG. TEST PAD
PWR. H.T.B. OFFIC
1 ACRE SOLAR POND
2 ACRE EVAPORATION POND
EXTG. FENCE
KEAHOLE POINT LIGHT HOUSE
OTEC & SURFACE WATER PIPES
PACIFIC OCEAN
0 50 100
SCALE: 1" = 100'
PROJECT LOCATION
KE-AHOLE POINT
MAUNA KEA
KAILUA-KONA
MAUNA LOA
0 6.25 12.5
MILES
KEY PLAN
ISLAND OF HAWAII
KE-AHOLE AIRPORT
PROJECT SITE
KE-AHOLE PT.
VICINITY MAP
KEAHOLE 1 ACRE 30 KW SOLAR SALT POND POWER PLANT
KEAHOLE SITE PLAN
SETS INC.
Scientific, Educational, Technical Services
Honolulu, Hawaii
SPOTEC 1

Figure III-2.

- a soil with good cohesion for strong pond walls
- easily compacted soil for structural stability
- deep ground water table to minimize bottom heat loss

Weather/Climate

- high incident solar radiation for good performance
- low wind-borne debris to maintain cleanliness
- low wind speeds to minimize wave action
- low evaporation to minimize make-up water requirements

Salt/Brine

- low-cost salt available nearby to reduce costs

Water

- easy access to fresh or low salinity water for pond establishment and surface washing
- an environmentally acceptable method to dispose of or recycle maintenance brine

Heat

- a use for the pond's stored heat energy

Some of the above criteria are, of course mutually contradictory. No site would meet all of the above criteria, so it therefore becomes a task to select a site with as many favorable criteria as possible with an eye towards cost reductions and performance enhancements wherever possible.

The Natural Energy Laboratory of Hawaii (NELH) as the site for the SPOTEC project can be reviewed in light of the above criteria. Major considerations in Hawaii for site selection are the land related criteria. With high land costs, especially along the coastline, a site such as the NELH with low land costs and supportive governmental policies, plans and zoning meets these important criteria. The very reason for the existence of NELH is to provide a place for conducting alternate energy research and development that minimizes the costs associated with land use acquisition and obtaining governmental approvals.

The NELH site does not offer ideal conditions in terms of the soil-related criteria listed above. The site does have excellent drainage and the basalt rock is dry and of low thermal conductivity down to the ground water level (sea level). However, pond construction will be more expensive than average because the fresh basalt rock is very difficult to excavate or even level and material must be imported to build up dikes to form an above-ground pond.

NELH receives high solar insolation and should provide for above average pond performance. The site also has fairly high evaporation and low rainfall which creates a requirement for a source of water for pond replenishment and wash water. This water can easily be provided from the ocean. The site has moderate or low wind speeds most of the year due to the lack of persistent trade winds along the Kona coastline. High evaporation at the site is not viewed as a negative factor since the brine production facility requires a favorable evaporation rate.

There are no local sources of salt available. However, the strong potential of producing brine at the site to stock the pond is an alternative that could replace in whole or part, the need to ship in a large quantity of salt from outside Hawaii.

A strong advantage of the site, and a major reason for its selection, is the availability of deep-ocean cold water for the condensor side of the power conversion cycle. This well improve performance by over 20%, and it represents an improvement on the current state of the technology.

The NELH can provide warm sea-surface water, deep cold ocean water and fresh water. The recycling of pond surface maintenance water appears possible with the inclusion of the brine production facility in the design. This would eliminate the need to dispose of this water into the ground.

The use of the pond's heat is not a problem since the facility is being designed to utilize this stored energy to generate electricity. Some of the electricity would be utilized by the pump's associated with the pond system, the balance can be utilized by the NELH.

Thus the site is excellent from the standpoint of performance because of the high insolation, low wind regime, low thermal conductivity soil and rock, the availability of deep-ocean cold water, and the availability of seawater and a high evaporation rate for salt production. The free land and government support is also an advantage. The only serious disadvantage is the nature of the surface and subsurface rock which will make pond construction cost high.

C. Existing Site Occupants

The Natural Energy Laboratory of Hawaii (NELH) consists of 328 acres of ocean front property located at Ke-ahole Point on the Big Island of Hawaii adjacent to the Kona Airport. This site is deemed to be one of the best in the world for ocean thermal energy conversion (OTEC) research.

NELH was established by the Hawaii State Legislature in 1974 as a facility for natural energy research and development. It is a nonprofit corporation managed by a Board of Directors.

OTEC-related experiments have been conducted at NELH since 1975. The official groundbreaking for the construction of permanent roads and facilities took place in January 1979.

NELH's first major onshore user is the Seacoast Test Facility (STF) Project. STF is a joint project of the State of Hawaii and the U.S. Department of Energy (DOE). STF is located on 5 acres near the tip of Ke-ahole Point. The STF is conducting research on OTEC biofouling and corrosion countermeasures.

NELH provided staff support and assistance for Mini-OTEC, the world's first at-sea closed-cycle OTEC plant to produce net energy. NELH obtained permits to allow Mini-OTEC to position itself in HELH's "ocean energy corridor," approximately 1,000 feet wide and 5,000 feet long, extending from Ke-ahole Point. Thus, NELH is the site of two of the nation's three major OTEC seawater experiments--STF and Mini-OTEC. The third major experiment, OTEC-1, was located 14 miles northwest of NELH.

The NELH Board is responsible for maintaining NELH property, reviewing and approving research proposals from prospective users, and planning and coordinating the development of the NELH site. With the approval of the Board, researchers may arrange to share existing facilities or construct their own facilities. Areas of planned expansion are OTEC, OTEC-aquaculture, and direct solar research.

The State-operated Ke-ahole airport borders the NELH to the east. At present, it serves as an inter-island facility with one operational runway. With the growth of tourism on the Kona-Kohala coastline traffic into and out of KeAhole airport now exceeds the international airport in Hilo. Facilities at the airport include terminals for inter-island airlines and commuter airlines, control tower, emergency services, car rental facilities and parking lots. Most of the airplane traffic into and out of Ke-ahole is between 6 a.m. and 9 p.m. daily. Most of the State-owned lands utilized by the airport are in the State urban district. There is however, a buffer of conservation district land running parallel to and just east of the NELH fenceline. The width of the buffer is approximately 1300 feet.

All of the land that borders the NELH is State-owned. Further south, the Kaloko-Honokohau area is privately owned. This area is rich in archaeological sites and has been proposed as a national historic park. However, very high land values have hindered the acquisition of this property to date. To the north of he State-owned lands lies vacant privately owned land mostly arid lava flows within the State-designated conservation district. The nearest residential area to NELH is several miles east, on the slopes of Hualalai.

The SPOTEC pond power plant, the one-acre solar pond facility, would be located entirely on the NELH site (see chapter VIII.A). The later, larger solar ponds may be located on the NELH site or on the Department of Transportation/airport site to the east of the NELH site, or partly on both sites (see chapter XVII).

D. SITE GEOLOGY

Ke-ahole Point is the western-most point on the island of Hawaii. It is located on Hualalai volcano--one of the five volcanoes which make up the subaerial portion of the island. Hualalai is a shield volcano which, as Hawaiian volcanoes go, has not yet evolved to a fully "mature" stage. The most recent activity was the lava flow of 1801 (MacDonald, 1972). Generally, its surface appears to be less than 4000 years old and much of the present surface formed primarily by thin-bedded basaltic lava flows. Pyroclastic (explosive) cinder and ash deposits occur--primarily on the east side and associated with the rift zones (Stearns and Macdonald, 1946). These deposits are less significant (in terms of volume) than more "mature" Hawaiian volcanoes such as Mauna Kea whose younger volcanism is dominated by pyroclastic actvity. Hualalai has been seismically active within historic time although the source of such activity (volcanic or tectonic) is not known.

The site is located a few hundred yards east of Ke-ahole Point (Site Plan, Figures III-1, 2) in an area of geologically recent pre-historic lava flows of Hualalai volcano. The distal portion of the lava flow of 1801 is located just north of the site. The vent of this flow occurred at the 1600 ft. level on Hualalai's northwest rift zone and reached the sea along the coast from just north of Ke-ahole Point northward to Mahaiula. The site is located on lava flows which appear to have vented somewhat to the south of the 1801 vent--south of the prominent NW rift. Based on their fresh appearance, the absence of soil and virtual absence of vegetation, it is estimated that these flows are less than 500 years old. These flows are pahoehoe type lava--characterized by a moderately broken and fractured rock formed by the solidification of liquid lava and some subsequent cracking primarily due to stresses developed during cooling.

Two flow units can be delineated on the surface at the project site. At the western end, a relatively smooth pahoehoe flow occupies the surface at elevations ranging from approximately 6 to 14 ft. The distribution of this flow is shown on the Photogeologic Map (Figure III-3)(based on air photo interpretation). The thickness of this flow is not known at this time, however its surface character indicates that the potential existence of lava tubes below the surface is a consideration during construction. (Lava tubes are conduits within the flow along which lava travels during flow movement. At the cessation of an eruption the tubes frequently empty--leaving voids sometimes tens of feet in maximum dimension.)

To the east, a younger pahoehoe flow overlies the western flow. Surface elevations on this unit range from approximately 12 to 18.5 ft. with tumuli locally as high as 22 ft. At its margin, and throughout the area occupied by the power pond site, this flow has a thickness in the 4- to 7-foot range. Its surface is broken by a number of lava channels--some of which are indicated on the Photogeologic Map. It appears that in the energy pond area, this flow is less likely to harbor lava tubes because of its limited thickness and the obvious presence of lava channels to carry the lava in lieu of tubes. However, these channels may reflect the existence of tubes below, which may or may not be of significant size. To the east of the energy pond, in the area of proposed salt production ponds, the surface character of this flow becomes smoother with possible flowback features suggesting that tubes are a potential problem.

Porosity of this rock is a consideration in estimating site thermal properties. Attention has been given to the variation in small scale structure which may control porosity. Gas bubbles (vesicles) in the lava vary in size and distribution within a given flow unit. Observation at the site suggests that a typical case may display three zones:

1) The surface scoria zone is usually very glassy and vesicular with porosity in the 35-50% range;

2) Beneath this glassy crust, a thin layer--generally less than a few centimeters--of numerous large vesicles is present. Porosity in this zone is very high.

3) The main part of the flow (perhaps 80% or more of the total thickness) shows gradational changes with vesicularity decreasing toward the center. In the upper part of this zone porosity may be in the

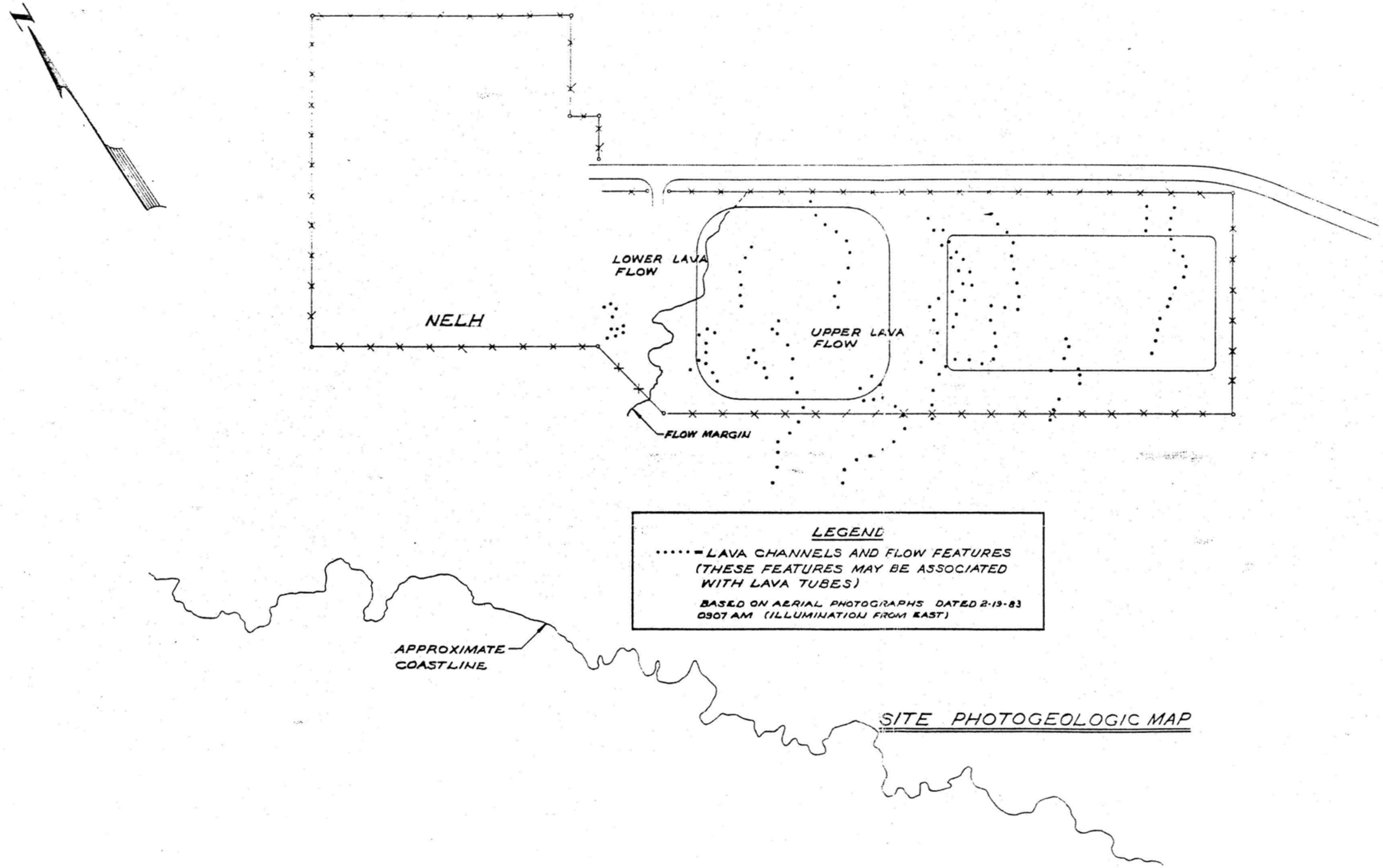


Figure III-3

KEHOLE 1ACRE 30KW SOLAR SALT POND POWER PLANT		
SITE PHOTO-GEOLOGIC MAP	SETS INC. Scientific, Educational, Technical Services Honolulu, Hawaii	SPOTEC 17

vicinity of 30%, decreasing to perhaps 5% in the middle, and reaching 25-30% at the bottom of the flow.

The above generalization notwithstanding, there is a wide range in the variations of vesicle distribution. In addition, the thermal properties of the near surface subgrade may also reflect higher densities due to reworking during site preparation and construction.

The features described above are typical of the relatively fresh pahoehoe lava flows which occur throughout the area of Ke-ahole Point. It is understood that no significant problems associated with lava tube collapse was encountered during site preparation and construction of the NELH facility (Fankboner, personal comm., 1983). For the present project, site preparation, including proofrolling, is expected to disclose significant tubes during construction so that appropriate corrective measures may be taken.

The surface material is a moderately broken and fractured pahoehoe lava. This material will, generally, be workable by a large bulldozer down to 1-3 feet. In some cases, particularly massive zones may be encountered which may require blasting, however this is not expected to be a dominant factor.

E. Oceanography

One reason for selecting the NELH site was Ke-ahole Point's proximity to deep cold ocean water. Water depth increases rapidly with distance from the shoreline, with depths of 2,500 feet within a mile of the coast. Several marine terraces with slopes of less than 30 degrees lie between the shoreline and 900 foot depth. Below 900 feet, the slope steepens to over 30 degrees.

The NELH cold water intake pipe extends down to approximately 2,000 feet. Nutrients are abundant in this deep cold water. Temperature of the water at this depth is approximately 48.7 degrees F (6.5 degrees C). The annual surface water temperatures range from 76.5 degrees F (24.7 degrees C) to 80.8 degrees F (27.1 degrees C) during winter and summer seasons, respectively.

Being sheltered from the normal trade-wind generated waves, Ke-ahole Point receives waves throughout most of the year below four feet (1.2m) in height with an average of approximately 2 feet (0.6m) with periods of 9-15 seconds. Larger waves can be generated by local "kona" storms, distant storms in the North Pacific or very rarely, by hurricanes in Hawaiian waters. Hurricane Iwa, in November of 1982 produced some waves that damaged the present NELH facilities facing the northwest. An estimate from theory for a maximum design wave height along this coastline is approximately 23 feet (7m) with a period of 14 seconds. The maximum tidal range in these Hawaiian waters is slightly less than three feet (about one meter).

Tsunami runup is a possibility along this coast. The published Flood Insurance Rate Map (FIRM), (Panel 681, dated May 3, 1982) for Ke-ahole Point shows areas of predicted 100-Year tsunami inundation. The proposed location of the SPOTEC facility lies inland of this designated zone and is located in Zone C, areas of minimal flooding (Figure III-4).

The nearshore waters around Ke-ahole Point are classified Class AA by the State Water Quality Standards. The management objective of this class is that these waters remain in their natural pristine state as nearly as possible with an absolute minimum of pollution or alteration of water quality from man-related sources or action.

Waters offshore of Ke-ahole Point are a popular fishing area for game species such as Pacific Blue Marlin. Fishing also occurs along the NELH coastline, mostly further north and south from the point itself, due to higher wave activity produced from wave refraction and reflection.

F. Vegetation and Wildlife

Vegetation at the proposed site is quite sparse and typical of xerophytic savanna/thorn scrub grassland. There are scattered clumps of exotic fountain grass (Pennisetum ruppelii) and a few noni (Morinda citrifolia L.) on the arid pahoehoe lava flow of the site. Between the project site boundary and the shoreline there is a strand vegetation zone. The plant species found in this zone are Naupaka-Kahakai (Scaevola taccada), along with hialoa (Waltheria americana) and beach morning glory (Ipomoea pes-caprae). Also found are clumps of kiawe (Prosopis pallida) and haole koa (Leucaena latisiliqua).

Wildlife is quite sparse on the project site. A few common introduced birds may visit the site. These are the common mynah (Acridotheres tristis), barred dove (Geopelia striata) and house finch (Carpodacus mexicanus). The introduced Indian mongoose (Herpestes auropunctatus), mice and rats may also visit the site.

No rare, endangered or threatened species of biota were observed on the site. There is a small possibility that the Hawaiian owl (Asio flammeus sandwichensis) and the Hawaiian hawk (Buteo solitarius) forage the site.

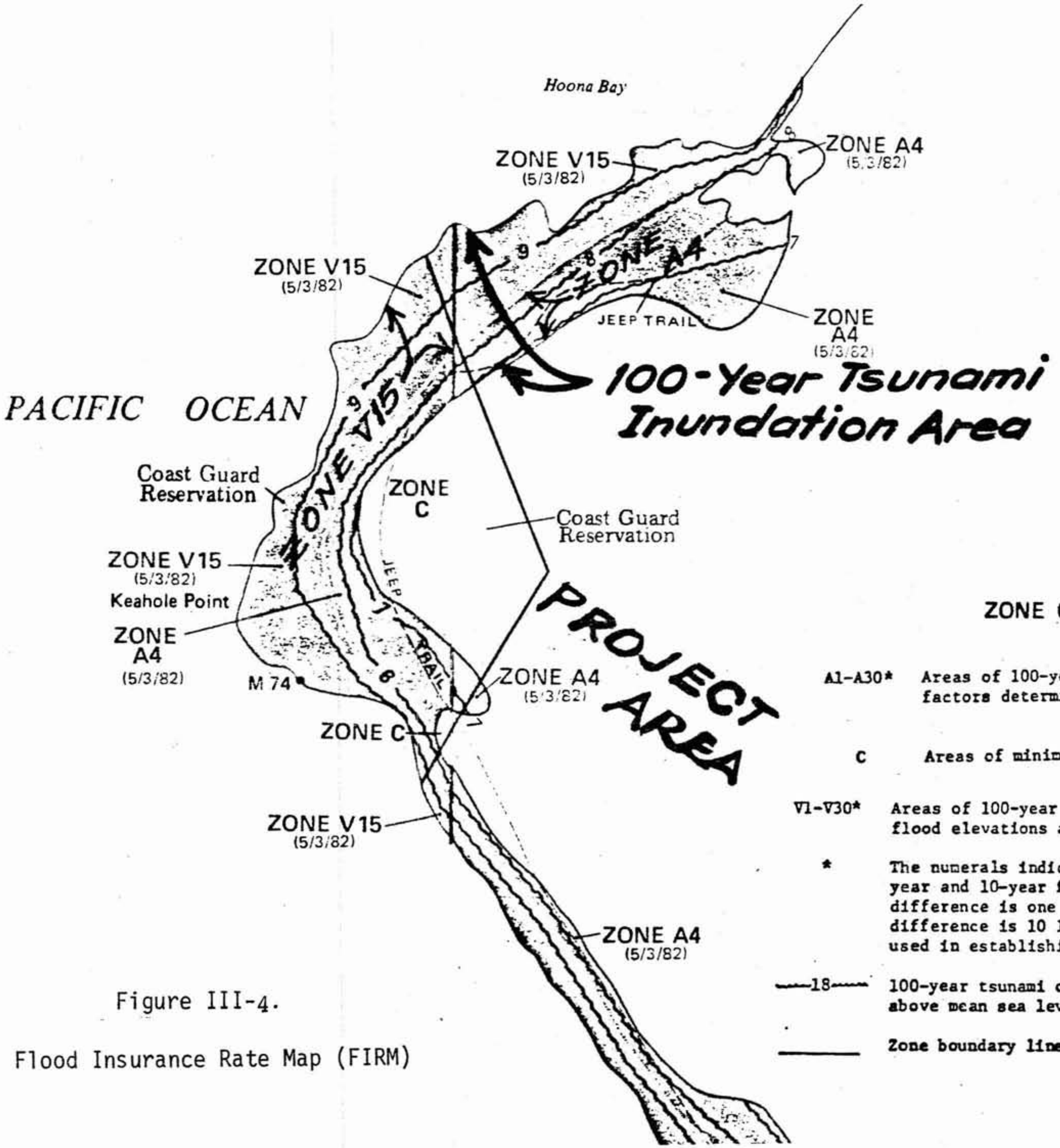


Figure III-4.

Flood Insurance Rate Map (FIRM)

ZONE C

A1-A30*	**Areas of 100-year flood, base flood elevations and flood hazard factors determined.**
C	**Areas of minimal flooding. (No shading)**
V1-V30*	**Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors determined.**
*****	**The numerals indicate the magnitude of difference between the 100-year and 10-year flood elevations. For numerals between 1-20, the difference is one half of the value; for values greater than 20, th difference is 10 less than the numerals shown. This information is used in establishing insurance rates.**
—18—	**100-year tsunami or riverine elevation line, with elevation in feet above mean sea level.**
———	**Zone boundary line**

IV. Environmental Data

A. Climate

The Ke-ahole Point area, and the Kona area in general have a different climate than other areas of the Hawaiian Islands. This difference is created by the location on the leeward side of several large mountains which interupt the normal tradewinds. The Kona region is the only area where summer rainfall exceeds winter rainfall and makes it more typical of a tropical climate than most other regions in Hawaii. Elements of concern to the project planning are discussed in the following sub-sections:

It should be noted that climate grades rapidly from the up-slopes of Hualalai to the north to the ocean shore at Ke-ahole Point. This existence of microclimates makes difficult extrapolation of measurements made near but not at to the exact project site. The tendency is for areas nearer Ke-ahole Point to be dryer and less cloudly than areas near the Ke-ahole Airport and on to the north (up slope).

Rainfall The Ke-ahole Point area is semi-arid with a median annual rainfall of 15" per year. Rainfall occurs only during a few days each month with a few heavy showers or a passing storm producing the majority of the rainfall. The summer months usually have a higher frequency of late afternoon or early evening showers than during the winter when the other regions of Hawaii receive their maximum rainfall. The median rainfall received at Ke-ahole is less than that received by the surrounding open ocean. This makes KeAhole an area where evapotranspiration greatly exceeds the incoming precipitation.

Recent rainfall measurements have been collected at NELH and are reported to the National Climatic Center. Table IV-1 summarizes the rainfall for 1981 & 82 and shows the variability in the rainfall, both monthly and year to year.

Temperature The temperatures are equable due to the small seasonal variation in the amount of solar insolation and the thermal inertia of the surrounding ocean. Average annual temperature at the site is 75 degrees F (23.9 C). The monthly average range is quite small, from 73 degrees F in January to 75 degrees F in August. The maximum daily temperature is 93 degrees F and the minimum 54 degrees F. The average daily temperature range of about 16-17 degrees F is larger than the annual range of 3 degrees F. Thus there are hardly any seasonal differences in air temperature that might affect pond performance like that on the U.S. mainland.

Relative Humidity Although the Ke-ahole site is arid, the relative humidity exhibits a range from 55% - 75% during

Table IV-1.

Ke-ahole Point Precipitation (in inches)

1981 Mo.	Total	1-day Highest	1982 Mo.	Total	1-day Highest
1	1.82	1.55	1	5.45	2.28
2	.32	.10	2	.10	.08
3	.61	.58	3	1.83	.86
4	--	--	4	.94	.67
5	.87	.37	5	1.41	.59*
6	.33	.27	6	2.15	.68
7	.30	.12	7	.47	.25
8	.10	.10	8	1.84	1.16
9	.08*	.08	9	.40	.10
10	.17	.12	10	1.39	.58
11	.15	.15	11	1.10	.61
12	3.07	2.80	12	1.95	.97
	7.82			19.03	

* Incomplete month of data.

the day due to the moist sea breeze which predominates during late morning and afternoon hours.

Wind A land-sea breeze wind pattern predominates in this area, with a weak offshore breeze from early evening to early morning. Predominant offshore breezes come from the east and northeast. With rapid heating of the lava landscape, the on-shore breeze picks up in the hours following sunrise and continues most of the day. The on-shore winds from the west and southwest are light to moderate (3.4 to 16.1 mph) with high frequency of occurrence during the summer months. The average wind speed is approximately 9.8 mph and with a direction of 220 degrees (southwest). Annually wind speeds greater than 25 mph occur quite infrequently and are usually associated with cold front passages, "Kona storms" or passing tropical depressions. Winds up to 40 to 60 mph can occur during unusual storms. Wind data for 1974 for the KeAhole Airport is shown in Table IV-2.

Evaporation Evaporation at the site is approximately 90" per year with a range of 46" to 135". This is an estimate based on pan evaporation measurements at other day leeward locations in the Hawaiian Islands such as the Ewa plain and discussions held with personnel of the State Division of Water and Land Development. Actual evaporation rates at the site have not been measured to date. It is believed that evaporation at the site would be higher except for the modifying effect of the on-shore breeze during daylight hours.

B. Weather

The predominant weather pattern at Ke-ahole Point is one of sunny mornings and middays with partially cloudy skies in the late afternoons, especially during the summer months. Daily extremes in the weather are rare, but do occur. These include local intense storms, cold front storms, "Kona" storms and tropical depressions.

Local intense storms typically occur in the late afternoon or early evening when there are well developed on-shore breezes, especially in summer. They are sometimes accompanied by thunder and lightning and even more rarely, waterspouts. These storms can produce periods of intense rainfall, usually nearer the mountain than the site.

Cold front storms occasionally reach as far south as the Big Island during the winter months. There may be locally heavy rains and gusty winds from the north and northwest.

"Kona" storms are also possible at Ke-ahole Point and are a feature of the winter season. Their number varies from none to several each year. They are so called "Kona" storms because

Table IV-2.

Ke-Ahole Point Wind Data

STATION: KE-AHOLE, Hawaii County
RECORD: 1 Jan 74 to 31 Dec 74 (daylight obs)
LOCATION: 19 45'N 156 03'W 13 meters MSL, 26 Ft Anemometer mast

				KNOTS					No.
Month	Calm	1-3	4-6	7-10	11-16	17-21	22-27	>28	Obs.
January	0.0	2.4	23.6	41.7	23.4	8.0	0.9	0.0	539
February	0.0	3.1	34.2	57.1	5.6	0.0	0.0	0.0	482
March	0.0	1.7	26.4	50.5	18.2	2.8	0.4	0.0	527
April	0.0	1.9	25.1	62.8	10.1	0.0	0.0	0.0	513
May	0.0	3.4	25.2	54.7	16.7	0.0	0.0	0.0	532
June	0.0	2.8	25.4	61.0	10.8	0.0	0.0	0.0	508
July	0.0	2.8	24.8	57.3	14.7	0.4	0.0	0.0	529
August	0.0	3.6	29.2	57.8	9.5	0.0	0.0	0.0	528
September	0.0	5.1	27.7	56.9	10.3	0.0	0.0	0.0	513
October	0.0	4.1	31.6	54.8	9.1	0.4	0.0	0.0	507
November	0.0	2.2	29.5	48.1	15.7	3.9	0.6	0.0	511
December	1.4	2.4	40.0	47.6	8.6	0.0	0.0	0.0	510
Annual Avg	0.1	3.0	28.6	54.2	12.7	2.3	0.2	0.0	6199

Percentage Frequency by Speed - Category in Knots

By University of Hawaii/Department of Meteorology, February 1980 they bring rain from the leeward, southwest directions. Rainfall is more widespread than a cold front storm and can be steadier and more prolonged. High winds (40-60 mph) may also accompany the storm and create damage. High surf can be generated by these storms and pound the Ke-ahole Point coastline, such as during January 8-10, 1980 which caused extensive damage to under water structures and coral populations in shallow waters.

Passing tropical depressions are most likely to occur the later half of the year, from July to December. True hurricanes are very rare in Hawaii with tropical storms (winds under 74 mph) being more frequent. The gusty winds and high rainfall of tropical storms are similar in nature to "Kona storms." The most recent hurricane (Iwa) of November 1982 did not strike KeAhole Point but did produce large waves which damaged some of the NELH facilities. If a major storm were to hit the Ke-ahole area the major damage would be from the winds and storm waves, rather than the rainfall, due to the site's highly porous lava.

C. Solar Insolation

The location of Hawaii in the tropics provides for high year-round solar insolation useful for solar pond power generation. The major local differences in the amount received is dependent primarily on the amount of cloud cover and nearness to mountains which cast shade on areas in the morning or evening hours.

Ke-ahole Point is a dry leeward coastal location with low amounts of cloudiness and high insolation. Solar insolation measurements have been collected at NELH, but inconsistently since 1976 due to equipment malfunctions. The available data was summarized and is shown in Table IV-3. The solar insolation averages for the thirty-five months on record is 461 (cal/cm /day). This average is biased towards the winter months of October to March. For the six winter months the average is 420 (cal/cm /day) and for the shorter record span of the six summer months it is 540 (cal/cm /day).

Long term solar insolation measurements are available in Hawaii with a forty four-year span and were collected at the former Hawaii Sugar Planter's Association Makiki experiment station in Honolulu. The data from this location is summarized in Table IV-4. The annual average mean value is 517.5 (cal/cm /day). The Ke-ahole site may also receiving approximately this amount.

For pond performance estimates the average value used was 484 cal/ cm /day with a maximum monthly value of 731 cal/cm /day and a minimum monthly value of 214 cal/cm /day. These maximum and minimum monthly values provide best and worst case estimates of the expected solar radiation received at the site. These maximum and minimum figures are based on recorded data from other stations. The recorded maximum and minimum monthly averages at Ke-ahole Point of 615.1 cal/cm /day (May 1978) and minimum 349.2 cal/cm /day (January 1982) fall well within the best and worst case values of available solar insolation.

Table IV-3.

Daily Solar Radiation (cal/cm^2/day)
Ke-Ahole Hawaii

YEAR		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
	Avg										458.2	393.1	397.2
1976	Max										541.4	495.4	446.6
	Min										278.5	146.7	265.6
	Avg	406.0	435.8	450.5	526.7	-	495.2	515.3	543.4	497.7	406.0	409.2	364.0
1977	Max	470.0	532.9	582.7	660.7	-	676.0	675.1	658.3	629.6	514.4	474.0	422.5
	Min	240.7	261.2	247.9	410.0	-	342.7	295.3	361.7	273.9	230.8	283.2	220.1
	Avg	410.1	512.1	524.8	551.8	615.1	562.7	565.7	544.0	520.1	475.2	382.5	360.1
1978	Max	480.5	575.8	627.1	680.1	730.9	706.6	688.3	682.9	644.8	566.0	485.0	442.4
	Min	290.7	332.0	313.5	349.1	344.8	345.7	384.7	259.3	321.5	331.4	69.9	154.5
	Avg	381.9	371.3	555.5									
1979	Max	482.7	556.2	635.0									
	Min	103.1	120.5	324.7									
1980	NO DATA												
	Avg											365.4	387.1
1981	Max											431.5	449.2
	Min											258.2	51.7
	Avg	349.2	457.1	397.5	548.0								
1982	Max	480.1	541.1	606.1	679.5								
	Min	40.7	221.9	-	296.6								

Reduced from data provided by Dr. Paul Ekern, University of Hawaii.

Table IV-4.

Solar Radiation
HSPA - Makiki Station
(44 years of record)
Elevation 50 feet
Units - cal/cm /day

ANNUAL:	Mean	S.D.	Minimum	Maximum
Average	517.5	30.6	440.5	563.7
January	380.3	37.1	291.0	441.0
February	444.8	41.2	358.0	533.0
March	507.6	53.2	407.0	612.0
April	563.4	48.3	464.0	646.0
May	603.0	47.9	482.7	697.0
June	621.6	48.8	516.4	706.0
July	620.4	45.8	524.5	708.0
August	611.2	47.0	500.7	689.0
September	574.5	40.7	475.7	650.0
October	490.3	40.3	412.0	574.0
November	408.8	37.6	321.2	475.0
December	365.8	32.2	303.2	426.0

(Source: How, 1978)

D. Cloud Cover

Cloud cover at Ke-ahole Point is associated with the daily land-sea breeze circulation and the short term occurances of larger storms. A typical day starts with clear skies and light off-shore winds. As the land heats up and the wind switches to on-shore, clouds form over in-land areas around Hualalai. During late afternoon hours scattered clouds may extend out to cover the site. Totally clear days are associated with light northerly winds during the winter months. At night the clouds dissipate and skies are clear and calm. During summer the frequency of cloud cover increases due to the better developed on-shore breeze during the mid-day and afternoon hours. Totally overcast skies can occur with infrequent major storms in the Kona region.

E. Air Quality

Air quality is a consideration in estimating pond performance. For example, particulate matter which may settle into the pond and affect water quality. Air quality is excellent at Ke-ahole Point with no major sources of dust or other particulates within several miles of the site except in the form of salt spray carried on-shore by the daily sea-breeze.

V. POWER NEEDS AND DISTRIBUTION

A. Introduction

The ultimate goal in the development of the SPOTEC power plants is to supply all the power for the NELH and the Ke-ahole Airport. The first (15/30 KWe) SPOTEC Plant will, of course, not produce sufficient power to do this but the larger pond is designed to meet this goal. Thus, it is appropriate to survey the power needs and usage of these two facilities at this time to help scope and direct the overall facility development. It is also desirable to determine the electrical system arrangement and how one might distribute power to these two facilities given the existance of the SPOTEC power plant(s). This is not an indepth study for that is not appropriate at this time nor under this contract.

B. The NELH

The NELH receives its electrical power now from the grid by way of a 12.47 KV line from the Ke-ahole Airport substation (see figures III-2). The NELH power usage at the present time is about 50-60 KW average load over 24 hours. Peak power needs are about 90 KW, with a daytime average load of approximately 70 KW. Dr. Tom Daniel of the NELH stated that the cost of running the pumps alone is about $800 per month. The NELH power usage will probably increase in the future dependent upon future projects located at the NELH.

The NELH has an emergency power supply consisting of three diesel generator sets of 125 KW output each. This equipment was obtained surplus from the federal government and has been used sporadically during grid power outages. The generator sets are built for intermittent use only and cannot be run dependably to provide baseload power.

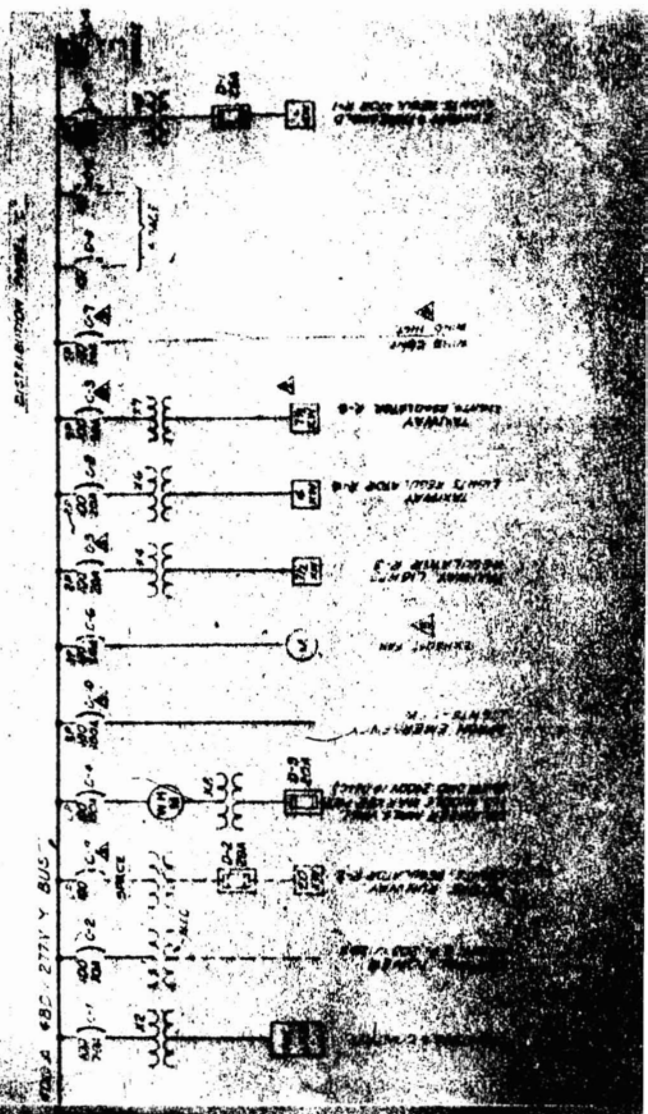
There is an automatic switching system to bring in the emergency generators when the grid power fails. This system is located within the NELH power center. It is suggested that the generators associated with the 15/30 KWe SPOTEC power plant be hooked into this switching network so that either solar power, diesel power or grid power can be selected. When the SPOTEC power plant is running reliably and its performance curve is well established, the sun could power a part of NELH.

C. The Ke-ahole Airport

The Ke-ahole Airport presently receives its electrical power from the grid. The power enters the load center and is from there distributed to two major circuits (Figure V-1). One circuit feeds the essential avaiation services, such as the control tower, localizer, and runway lights. The other circuit feeds the terminal buildings. The average consumption is about 215 KW with a higher, unknown, peak between six- and nine-o-clock in the evening.

The 300 KWe facility appears to be capable of providing sufficient power to present and at least near-future airport needs on a permanent basis. This would require that a power distribution line be run from the SPOTEC power plant

PLEASE NOTE: Only a very poor quality copy of this drawing (really two drawings combined into one here) was available. The best reproduction possible is given here to at least make the construction and planning personnel aware of the existence and general nature of the drawing.



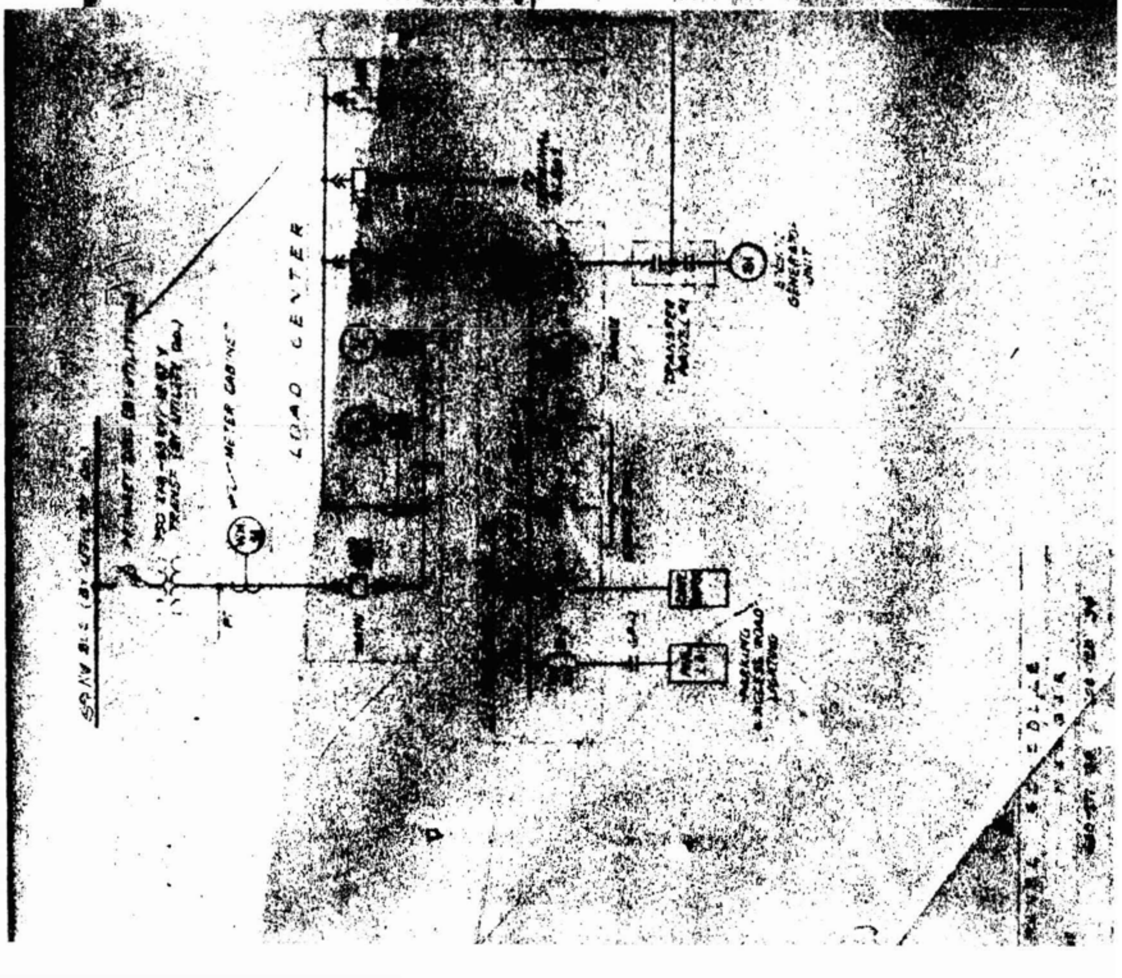


Figure V-1.
Ke-Ahole Airport Electrical Power Distribution

to the airport power distribution center. The distance is short but the line may have to be layed under the runways, depending on the exact location of the larger SPOTEC facility. There is presently a 12 KV power line between the airport and NELH which passes under the runways through a duct. It is not clear at the present time whether this duct is large enough to handle the larger power load or whether an additional duct would have to be added.

It has been suggested that the 15/30 KWe SPOTEC power plant power some part of the terminal buildings as a demonstration project. While there is sufficient power capability to do this, examination of the airport electrical schematics indicates that this would require some rewiring and/or new wiring of both the airport and the NELH ends of the existing power line between the two facilities. The location of that power line is shown in Figure III-2.

VI. PERMITS AND ENVIRONMENTAL REVIEW

A. Introduction

The environmental review and permits potentially required to implement the SPOTEC facility at the Natural Energy Laboratory of Hawaii (NELH) site were researched. This section briefly discusses these potential requirements.

Bibliographic research and discussion with the permitting agencies were conducted to obtain information on potential requirements. A checklist was utilized to screen out the permits which were clearly not necessary for the SPOTEC project. The remaining permits and clearances are then either automatically required or may be required, subject to a determination during the construction phases dependent upon the existing permits for the NELH and the exact nature of the SPOTEC project then.

The NELH has been established to provide a nearly ideal site to conduct alternate energy research. Land use designations, plans and zoning have been obtained so that this work can be conducted. Therefore, the major land use approvals, such as land use boundary district amendments, conservation district use or zoning changes do not apply to the initial SPOTEC facility. This saves considerable time in the obtaining of necessary permits.

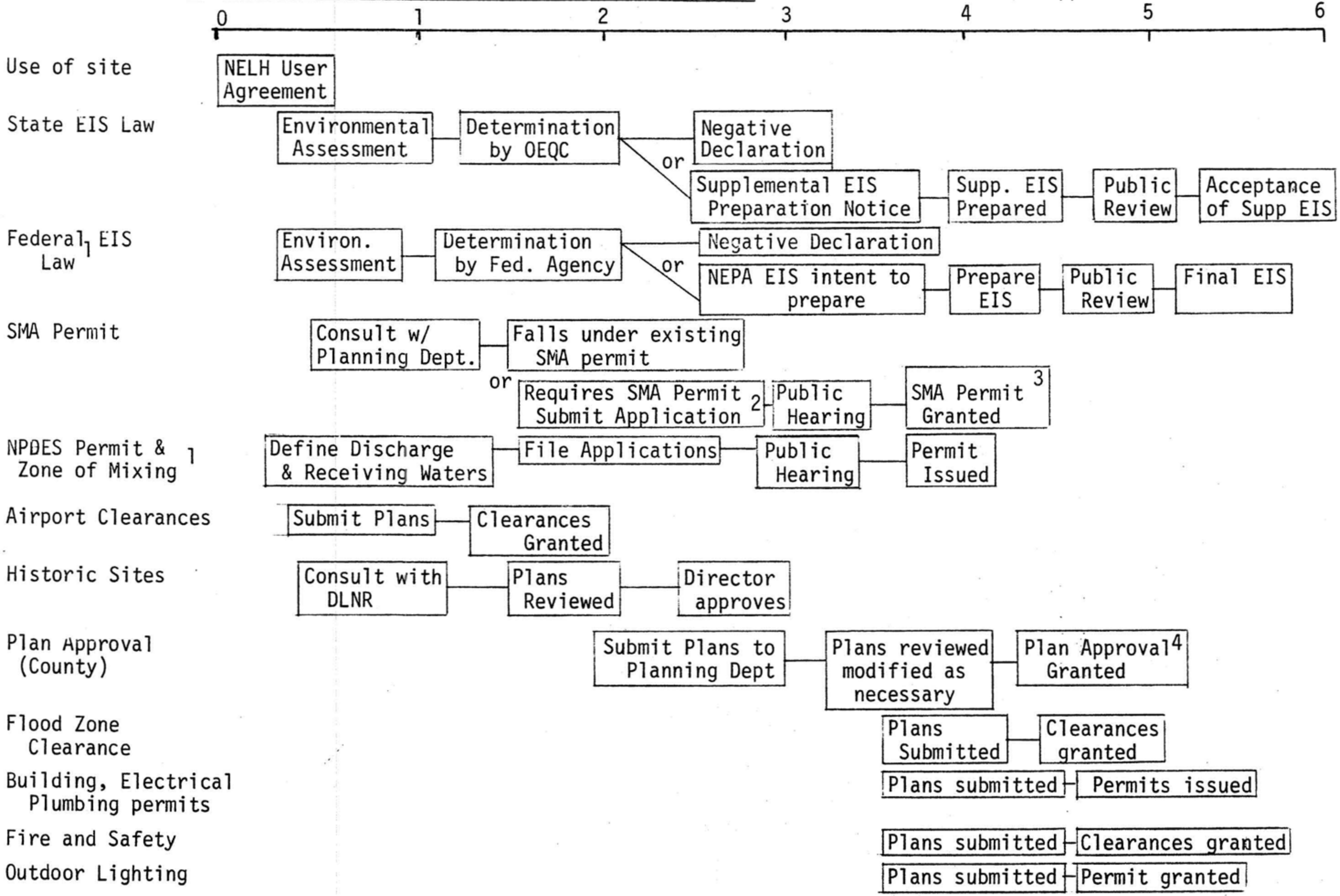
The sub-sections that follow discuss the permits and environmental assessments that are required or may be required for the SPOTEC project. Uncertainty of the necessity of some of the requirements stems partly from the yet-to-be determined source of funding for the subsequent phases of the project. Also, since there are existing permits for OTEC related research, some of the potential permits may not be required. The sequence of the following subsections reflect their relative importance and timing in preparation and obtaining of the environmental clearances and permits. This sequence is shown graphically in Figure VI-1.

B. NELH User Agreement

The proposed construction and operation phases of the project will require the agreement of the NELH Board of Directors for the use of NELH facilities and/or services. Discussions would be held with the NELH Executive Director to formulate a document that would include an explanation of the purpose and objective of the proposed project, a description of what will be done, how and when it will be done, and what role the NELH is expected to play in project support. The description of the project would at a minimum provide the duration of the project, area to be used, structures, utilities support to be provided by NELH, permits required and how they will be obtained, a liability clause protecting the NELH, a default clause and a statement of the fees that will be charged by NELH for the facilities and services provided. For small projects a simple facilities use agreement is worked out. For larger complex projects a formal contract may constitute the user agreement.

The review would be based on the relationship of the project to the general area of development of natural energy resources and also upon its utilization of the resources available at NELH and Ke-ahole Point. A SPOTEC

Figure VI-1. Sequence for Environmental Assessments and Permits



Notes:
1. If required.
2. The SMA permit application must include an accepted EIS if one is required.
3. Approval of other permits must follow issuance of the SMA permit if required.

power facility would clearly fall under alternate energy development and would make considerable use of the sites high insolation, deep cold seawater and available land.

The NELH Board of Directors was approached by SETS, Inc. for designation of a specific site for the facilities and the Board formally assigned the specific site used in this design (see letter, Chapter III).

C. Environmental Review

1) Ke-ahole SPOTEC Project--Environmental Assessment Requirements State Environmental Impact Assessment Requirements: Chapter 343, HRS.

The proposed project falls within the requirements of the State EIS law, Chapter 343, HRS . The proposed use of State owned land triggers the requirement. Since the Natural Energy Laboratory of Hawaii went through the full EIS review process and had an EIS accepted, the present project will not require the preparation of a completely new environmental impact statement. The proposed project will require the preparation of an environmental assessment and a determination on whether a supplemental statement will or will not be necessary.

Usually the agency or applicant proposing the project is the one that prepares the assessment. The basic outline of an environmental assessment is as follows:

a) Name of applicant or proposing agency.
b) Name of accepting authority, if applicable.
c) Names of agencies consulted in making the assessment.
d) General description of the project's technical, economic, social and environmental characteristics.
e) Summary description of the affected environemnt, including suitable and adequate location and site maps.
f) Discussion of the assessment process.
g) Identification and summary of major impacts and alternatives considered, if any.
h) Proposed mitigation measures of major impacts, if any.

If no former EIS had been prepared for the project or area, then the agency proposing the project makes a determination on whether the project will have a significant effect on the environment as outlined in the EIS regulations. However, since NELH already has an accepted EIS, the accepting authority, in this case the Governor through the Office of Environmental Quality Control, (O.E.Q.C.) must review the assessment and make the determination on whether a supplemental statement is required. If O.E.Q.C. determines that a supplemental statement is not required, it will file a Negative Declaration with the Environmental Quality Commission (EQC). EQC then publishes the determination in its EQC Bulletin . The publication of a Negative Declaration is the final step required for a project which receives this determination. The processs of preparing an assessment and obtaining a deterimnation can take one or more months depending on how much of the required information for the assessment is available beforehand. Following publication in the EQC Bulletin , the project proposer can then proceed to obtain the necessary permits.

However, if O.E.Q.C. determines that a supplemental statement is required, then they will have an Supplemental EIS Preparation Notice published in the EQC Bulletin . This announcement begins the EIS preparation and review procedures. The procedures are two-fold, in that a preparation notice is available for review and comment, then followed by the actual EIS preparation. Once prepared, the EIS is filed with the EQC and circulated for review for 30 days. Written comments are received and responded to in writing. A Revised Supplemental Statement is then prepared and filed with OEQC for their review and acceptance. Announcement of the availability of the statement for review and the acceptance of the Statement are published in the EQC Bulletin . Publication of the acceptance is the final step in this process. The time period involved in the preparation, review and acceptance of an EIS can take a minimum of four months.

2) National Environmental Quality Act (NEPA) Requirements

The requirements of the National Environmental Policy Act of 1969 (NEPA), Public Law 91-190 may have to be met if there is federal funding of the project or if a federal permit is required. The requirements of NEPA are similiar to those of the State's EIS law (Chapter 343, HRS). Whether a project requires the preparation of an Environmental Impact Statement depends on the determination by the appropriate federal agency if the project constitutes a major federal action significantly affecting the quality of the human environment.

General guidelines are provided by the President's Council of Environmental Quality. Each federal agency is required by these guidelines to implement the requirements of NEPA through their own set of regulations. If, as an example, funding were to come from the Department of Energy then their regulations implementing NEPA would have to be followed. The content of environmental assessments is fairly standard amoung the agencies but there are some procedural differences. An example of a project at NELH which had to meet NEPA requirements and the Department of Energy regulations is the Sea Coast Test Facility for which an environemntal assessment was prepared. The DOE did not require a full environmental impact statement for that project.

Each agency has an office assigned to see that the requirements of NEPA are addressed by that agency and private applicants seeking their federal permits. That office would be the point of contact to initiate the meeting of NEPA requirements for the project. If an EIS is required under NEPA as well as under the state EIS law, then the two requirements should be met by the preparation of a single document. The time required for preparation of a full EIS meeting both requirements could be six months or more.

D. Special Management Area (SMA) Permit

The Hawaii State Legislature enacted the Coastal Zone Management Act (Chapter 205A, Hawaii Revised Statutes) in order to establish state policy to preserve, protect, and where possible, to restore the natural resources of the coastal zone of Hawaii. The act established policies and guidelines which the counties follow in implementing the act.

Special Management Areas (SMA's) were defined by the counties to include at a minimum the coastal lands within 100 yards of the shoreline. Within the

SMA's all developments as defined by the act are required to obtain a permit under the rules established by the designated county agency. For the Big Island the Planning Department administers the SMA permit process. The entire NELH area and the KeAhole airport are within the SMA, with the main boundary being the highway.

Any projects costing less than $25,000 and having no significant effects qualify for a minor permit. Otherwise, developments require a special management area use permit. The applicant must present sufficient data to demonstrate that the project will not have any substantial adverse environmental or ecological effect, except where the adverse effect is minimized to the extent practicable and clearly outweighed by public health, safety or compelling public interests. The project must also be consistent with the SMA objectives and policies of the CZM Act and the county general plan, zoning and subdivision codes and other applicable ordinances.

The meeting of the requirements of Chapter 343, HRS, the State EIS law by agencies usually precedes the filing for an SMA permit. Therefore for the OTEC-assisted solar pond project the preparation of an environmental assessment and the making of a determination by the Office of Envionmental Quality Control, as discuseed under the state EIS law requirements above, would precede the submittal of information to the County Planning Department for their decision on the need to apply for an SMA Permit for this project.

It should be noted that the NELH and the Research Corporation of the University of Hawaii (RCUH) have been granted an SMA permit for Ocean Energy and Allied Research and Development Facilities on the lands set aside for the NELH. The effective date of the permit is November 16, 1978 and its purpose was to allow for the establishment of research and development facilities which are essential to the study of an alternate energy source, namely ocean thermal energy conversion (OTEC). The permit (SMA Use Permit no.77) states, "Further, any additional development other than that for which is authorized by this permit will be reviewed as proposed." The permit contained specific conditions reqarding archaeological surveys and the meeting of other permit requirements.

If an SMA permit is determined to be needed for the SPOTEC project then an SMA Permit Assessment Form would be filed with the County Planning Department. There is a $100 filing fee to go along with this application. The project would be considered by and would require the issuance of an SMA Use Permit by the Planning Commission. The time from filing to final action may take up to four months in addition to the time required to prepare an environmental assessment or a supplemental EIS if it is determined to be needed. As part of the SMA permit process, a public hearing is required to be held by the Planning Commission between 21 and 90 days after the application is filed. The hearing would be held in the Council district where the project is proposed. The Planning Commission must act on the permit within 30 days after the conclusion of the hearing. Issuance of an SMA permit, if required, must precede any other necessary land use approvals or permits.

E. NPDES and Zone of Mixing

1) National Pollution Discharge Elimination System (NPDES) Permit

An NPDES permit may be required for the project if an effluent discharge is to occur from the project to the coastal waters. The state Department of Health administers the NPDES program in Hawaii for the Environmental Protection Agency. The Pollution Technical Review Branch is the branch that reviews and issues the NPDES permits. These permits implement the Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500 and the State law, Chapter 342, Part III, Hawaii Revised Statutes.

There is an existing NPDES permit for OTEC activities at the NELH. The permit allows the discharge of small quantities of chlorine in a discharge up to 2000 GPM. Sampling and quarterly reports to the Department of Health are required. The OTEC-assisted solar pond project could possibly be included under the existing NPDES permit if it appears there is a need to discharge chlorine treated water into the ocean through the existing discharge facility. The proposed discharge of the OTEC-assisted solar pond chlorine treated wash water would be into the brine production-evaporation pond system, essentially making it a closed system.

Required information for an NPDES permit includes a physio-chemical characterization of the effluent, including nitrogen and phosporous, pH, temperature and other factors which differ from the quality of the receiving waters. A standard federal form is available from the Department of Health and is submitted with a filing fee of $100.00.

The Department of Health is required to notify the public of the Department of Health's intent to issue a permit usually through a public notice printed in a local newspaper. If requested by the public, a public hearing would be held to discuss the permit.

The issuance of an NPDES permit is for a set period of time, usually five years with a possibility of renewal. A monitoring program could be requried and involves at a minimum quarterly sampling of the effluent and its makeup. For major dishcarges a complete EIS could be required to provide the necessary data before issuance of a permit.

2) Zone of Mixing Approval

If the proposed project discharges effluent into the ocean in a quantity or concentration where the water quality standards for that area would be violated then a Zone of Mixing application would need to be submitted. The discharges presently permitted under the existing NPDES permit for the NELH did not require the issuance of a zone of mixing.

If required, the application would be submitted to the State Department of Health on their form. The application form has to be supported by a complete and detailed description of present conditions, an explanation of how these conditions do not conform to standards, and other pertinent information. Applications are reviewed on the potential effect on the established water quality standards for the area as specified in Chapter 54, of the Department of Health Rules. A public hearing in the county where the proposed project is located is required before a decision is made on the application.

The Zone of Mixing can be granted only if the application and supporting information clearly show that:

a) the operation involved in the discharge is in the public interest;
b) the proposed discharge does not substantially endanger human health or safety;
c) compliance with existing water quality standards would produce serious hardships without equal or greater benefits to the public; and,
d) the proposed discharge will receive the best available demonstrated pollution control technology, processes and operating methods.

The maximum time period for a zone of mixing cannot exceed five years. The person granted the zone of mixing may be required to perform effluent and receiving water sampling and report the results of each sampling to the Director of Health. The Federal Environmental Protection Agency must also concur with the issuance of the zone of mixing. The time frame involved can be six months from submittal of the application to issuance of the zone of mixing.

F. Airport Related Clearances

1) Federal Aviation Administration Rules on Objects Affecting Navigable Airspace

The FAA requires that persons who intend to make any construction or alteration near airports notify the FAA in writing so that it can determine whether or not the proposed project will affect navigable airspace. This is defined as the safe and efficient use of airspace. The FAA reviews the submitted material and issues a hazard determination or no hazard determination as appropriate.

In Hawaii, requests are submitted to the U.S. Department of Transportation, Federal Aviation Administration, Pacific-Asia Region. The request would be in letter form with a set of suitable drawings showing the project in plan, profile and in relation to the airport. The applicable Rules are found in 14 CFR Part 77.

2) Compatible Land Use

The Federal Regulations regarding grants to public airports requires that the airport operator (the State of Hawaii Department of Transportation) take appropriate action to the extent reasonable to restrict the use of land adjacent to or in the imediate vicinity of the airport to activities and purposes compatible with normal airport operations, including landing and take-off of aircraft. The proposed project falls within the existing zoning designations and uses established for NELH.

3) Obstructions to Air Navigation

The State of Hawaii Department of Transportation regulates the areas of land or water designed and set aside for the landing and take-off of aircraft. The land is also to be utilized in the interest of the public for such purposes. The regulations cover any natural or manmade object of both a temporary or permanent nature, including equipment or materials used therein. It also includes the alteration to any permanent or temporary structure by a change in its height or lateral dimensions, including equipment or materials used therein.

A permit may be required for an "airport hazard" defined as: "Any structure or tree which obstructs the air space required for the flight of aircraft in landing or takeing off at an airport, or any use of land which creates a dangerous condition. There is no filing fee.

The application would indicate the purpose of the project for which the permit is desired, with sufficient detail so that it can be clearly determined that the resulting structure would conform to the established height limitations or whether the resulting use violates the use restrictions established in Section XIV of the Airport Zoning Regulations. The Director will grant the permit unless it would allow the construction, maintenance or creation of an airport hazard.

The use restrictions say no use may be made of land within any zone established by the regulations or within the vicinity thereof which would:

a) Create electrical, electronic or atmospheric interference with radio communication or landing aids between an airport and an aircraft;

b) Make it difficult or confusing for operators of aircraft to distinguish between airport lights and non-airport lights;

c) Result in glare to or blinding of the eyes of operators of aircraft approaching or taking-off from an airport; and,

d) Impair visibility in the vicinity of an airport or otherwise endanger the landing, taking-off or maneuvering of aircraft.

G. Historic Site Review

The Department of Land and Natural Resources administers the state law (Chapter 6, Hawaii Revised Statutes) pertaining to historic and archaeological sites. Persons proposing to work in registered historic sites must notify the historic sites section ninety days in advance of the proposed start date. Also projects involving state lands, such as NELH, require a survey to determine the presence or absence of historic/archaeological sites on the property, usually identified with Tax Map Keys.

Any environmental assessment prepared for the project would need to address the presence/absence of historic/archaeological sites within the project area. Clearance from the Division of Historic Sites is usually through the submittal of a letter notifying the division of the project, its nature and location. Clearance to proceed is usually given if a walk-through survey by an archaeologist turns up no visual remains of historic/archaeological interest. (Note: there have already been several walk-through surveys of the NELH area.) The clearance usually contains a condition that if during construction, any historic/archaeological evidence is uncovered the division should be notified immediately so they may prescribe proper actions to follow.

The protection of historic resources is one of the objectives of the

State Coastal Zone Management Act (Chapter 205A, HRS). The County of Hawaii Planning Department implements the CZM law for the Big Island, and therefore also has an interest in any historic resources at the project site. Their concerns are addressed through the Special Management Area (SMA) permit process and in the plan review process.

If federal funds are used or federal permits are required for the project, the federal historic review requirements may also apply. The area that may be impacted by the project would be surveyed by an archaeologist to identify cultural properties eligible for inclusion in the National Register of Historic Places. The requirements are found in "The Procedures for the Protection of Historic and Cultural Properties" (36 C.F.R. Part 800). Following the survey, if the federal agency finds, in consultation with the State Historic Preservation Officer, that the undertaking will result in an effect on any property included in or eligible for inclusion in the National Register it is required that the Advisory Council on Historic Preservation be allowed to comment on the project in accordance with the Council's procedures.

H. County Level Permits

1) Plan Approval

The proposed project's plans must be submitted to the County of Hawaii Planning Department for review and comments. No structure can be erected, no use may be established and no significant development or improvement of structures or of land may be carried out unless plan approval has first been secured for the structure, use, development or improvement. The plans must include at a minimum the following information: site plan showing the location of the building and other structures; setbacks; parking layout and landscaping; floor plans; and, exterior elevations. There is no filing fee required.

The Director of the Planning Department has to consider the application together with all accompanying data within forty-five days after filing of the application. He would either deny, approve, or defer the application subject to conditions or alterations. If conditions or alterations to the plans are required, then the time-frame for obtaining plan approval would obviously be longer. The proposed use is reviewed in relation to surrounding property, improvements, streets, traffic, community characteristics, natural features, and in any other manner in order to assure that there are adequate light and air, proper siting and arrangements of all structures and improvements and that existing and prospective traffic movements will not be hindered. Also, the plans are reviewed to insure that the use is properly landscaped commensurate with the use and its surroundings, that unsightly areas are properly screened or eliminated, that there is adequate off-street parking to serve the use, that the access to the parking area will not create accident hazards and that within reasonable limits, the natural features of community value are preserved.

The granting of plan approval must precede the submittal of plans and applications for building, electrical, plumbing and grading permits.

2) National Flood Insurance

In order for the County of Hawaii to qualify for the federally subsidized flood insurance program, plans are reviewed for conformance to standards adopted under the program. The County of Hawaii Planning Department reviews the zoning aspect of the plans. The Department of Public Works, Bureaus of Plans and Surveys, Building Construction and Inspection, and Sewers and Sanitation review the plans and specifications for approval and issuance of applicable related permits. The proposed project's plans are reviewed in relation to the established flood hazard map for the area.

The 100-year tsunami inundation area or coastal flood plain is divided into Zone V15 or Coastal High Hazard Area with velocity or wave action, and into Zone A4 or the inland tsunami flood limits. The 100-year event has a one percent chance of being equalled or exceeded in any given year. Areas of minimal flooding are given a Zone C designation. In correspondence from the U.S. Army Corps of Engineers to SETS, Inc. the proposed solar pond project was stated to be in Zone C of the Flood Insurance Rate Map (FIRM) Panel 681 of 1900, except for the existing sea water pipes which the pond would utilize for its source of sea water.

3) Grubbing, Grading, Excavation and Stockpiling Permit

County of Hawaii Ordinance No. 168 established the requirement for obtaining a grubbing, grading, excavation or stockpiling permit in order to provide standards to safeguard property, control erosion and sedimentation and to promote public welfare by regulating and controlling excavation fills, grading, grubbing and stockpiling operations.

The proposed project's plans have to show:

a) all pertinent terrain features;
b) layout and anrrangement of the proposed works in plan view;
c) representation to scale of typical cross sections of cut and fill areas;
d) details of topography both before and after the proposed work;
e) indication of means to be employed to assure erosion control;
f) estimates (in cubic yards) of the amounts of cut and fill to be produced; and,
g) if material is to be imported to or exported from the site, an indication of where the material comes from or where it will be deposited. (Note: A grading permit is also required for any such offs-site locations as well.)

This is usually accomplished in the form of a scale drawing, with explanatory and/or supplementary data presented in the margins of the figure. The plan must be prepared by a civil engineer licensed in the State of Hawaii. After review of the plan by the staff, the signatures of the Division Chief and the Director are required. The signed plan goes to the permit section, which requires a performance bond in an amount determined by the amount of earth to be moved. A temporary erosion control plan must also be submitted and signed by the Division Chief and the Director and submitted to the permit section. The permit is usually obtained by the contractor doing the site work. The plans are also referred to the Planning Department for review of potential impact to historical/archaeological resources.

Fees for the permit go up in relation to the quantity of earth moved.

Notice must also be given to the Public Works Department before construction may begin, so that arrangements may be made for on-site inspection of the project. The time from filing to final action is about two to three weeks assuming no problems arise during the review.

4) Building, Electrical and Plumbing Permits

The County of Hawaii Department of Public Works, Bureau of Building Construction and Inspection issues the code-required building, electrical and plumbing permits. All proposed work must conform to the Uniform Building Code, published by the International Conference of Building Officials, the National Electrical Code, published by the National Fire Protection Association and the Uniform Plumbing Code, published by the International Association of Plumbing and Mechanical Officials. The Bureau reviews the plans and specifications of all building, electrical and plumbing works and issues the permits upon payment of the fees as determined by the Code for the specific trade work. The work performed would be inspected and approved by the Department of Public Works.

5) Building Plan Approval (Fire)

The County of Hawaii Fire Department implements the regulations established to provide minimum standards in regards to fire and life safety features for new and existing facilities. These regulations include the Rules and Regulations of the Fire Marshall, State of Hawaii 1964; the NFPA Flammable and Combustible Liquids Code No. 30 1963; the Life Safety Code 1967, NFPA No. 101; and NFPA Electrical Code No. 70 1968. Flammable liquid and LPG permit fees are processed at the Central Fire Station in Hilo. Plans and specifications for the project would be processed by the plan checker at the Department of Public Works.

6) Outdoor Lighting

If the project has outdoor lighting, then the County of Hawaii Department of Public Works would review the plans under Ordinance No. 38 in order to control the harmful effects of scattered light into the atmosphere to help preserve the the unique qualities of mountain top areas for astronomical observations which would be impacted by uncontrolled light brightening of the sky. The development plans should provide for shielding and filtration in order to minimize light impacts. The Bureau of Building Construction and Inspection (all lighting except street lights) reviews and approves the plans and specifications that are submitted. The installed lights would be inspected and receive the approval of the Department of Public Works.

I. Summary

The sub-sections above discussed the potential assessments and permits related to implementing the SPOTEC facility. They can be broken down into two listings, those that probably will be required and those that might be required based on the nature of the project and their relationship to existing NELH facilities, permits and clearances.

The following lists those assessments, permits and clearances that appear to be required:

NELH User Agreement
Environmental Assessment & Determination
   of need for a supplemental EIS.
   (Under Chapter 343, HRS , State EIS Law)
Airport related clearances
   --F.A.A. - Objects affecting navigable airspace
         Compatible land use
   --State Department of Transportation,
         Obstructions to air navigation
Department of Land and Natural Resources
   --Historic Site Review
County of Hawaii, Planning Department
   --Plan Approval
County of Hawaii, Department of Public Works
   --Flood hazard
   --Grading, Grubbing & Excavation Permits
   --Building, Electrical & Plumbing Permits
County of Hawaii, Fire Department and Public Works
   --Fire & life safety factors

The following are those clearances and permits that might be required:

Supplemental EIS to the accepted EIS for NELH

Environmental Assessment under the National
   Environmental Policy Act (NEPA)

Special Management Area (SMA) Use Permit

NPDES Permit -- State Department of Health

Zone of Mixing -- State Department of Health

Outdoor Lighting -- County of Hawaii, Department of Public Works

The sequence of events for meeting environmental assessment and permit requirements is shown in Figure VI-1. An approximate time line is provided but is highly dependent on agency processing times and determinations on several of the possible permits.

J. Potential Environmental Impact

The potential environmental effects from the construction and operation of SPOTEC at the NELH is discussed here. Environmental impacts can be either beneficial or adverse and be either directly or indirectly related to a project.

Construction of SPOTEC will create minor impacts, both on and off the project site. The site work consisting of grubbing, grading and berm construction will remove the existing sparse vegetation and displace any wildlife which may utlilize the area (very little). No endangered species of plants or animals will be affected by the project. Construction related traffic and equipment will temporarily lower ambient air quality through exhaust emmisions and the generaton of dust. Standard mitigation measures could be employed including the control of dust by watering or other methods in conformance with state air pollution control regulations of the Department of Health. Constructon noise genereated by the use of construction equipment will be mitigated by mufflers.

The open space character of the site would be altered. The SPOTEC facility would become a dominant feature along the stretch of access road just before entering the present NELH facilities. The brine production ponds and the outer embankment of the solar pond and supporting facilities would be in view from the access road.

Access along the shoreline would not be affected since the project boundary lies inland of the shoreline "jeep" trail. Access points to this shoreline trail occur at locations other than the project site.

Solar pond operation results in no waste products or adverse environmental impacts. It is a relatively benign operation, especially when compared to a coal or oil burning power plant. Water would be lost due to evaporation and would be replaced by seawater. Routine operation of the pond would include treating the power pond water with a biocide, most likely chlorine in a very small quantity (1.5 ppm) to prevent algae growth. Surface wash water from the power pond would be routinely returned to the evaporation pond.

The greatest potential impact is the unintended loss of pond brine due to a leak in the pond. Catastrophic failure of the embankment would release the hot brine to the subsoil where it would mix with the ocean water. Because the subsurface rock is very porous and because the ocean water moves relatively freely through the subsurface rock below the pond, brine lost would quickly be diluted and lost to the ocean. The residual chlorine dissolved within the brine would also be released to subsurface waters and would be further diluted. The degree of impact on the biota would be highly dependent upon the final concentration reaching the biota. The loss of brine could be possibly mitigated by immediately transferring the storage zone brine to the evaporation pond. This would reduce the loss of pond brine but not the stored heat.

There is little noise associated with the power conversion equipment. Vibrations and gaseous emissions would be virtually non-existent.

Safety is a concern due to the potential for drowning or burns if someone was to fall into the pond. A fence would mitigate this problem. There is an inherent tendency of the pond to inhibit objects from sinking, which is due to the higher density water at the lower levels of the pond. The upper three feet (1m) of water is not very hot and a person could get out of the pond without injury or serious disturbance to the pond.

VII. CONCEPTUAL DESIGN OF THE 15/30 KWe SPOTEC POWER PLANT FACILITY

A. Introduction

The conceptual design effort for SPOTEC was undertaken in order to develop a basis for the engineering design of the entire solar pond power plant facility and to ascertain at an early date if any serious technical problems were present. The results of the conceptual design were positive: no major technical problems were discovered.

The purpose for the facility are:

* to provide power to NELH and perhaps to Ke-ahole Airport
* to develop an engineering and technology basis to construct and operate a 300-600 KWe pond plant to supply the Ke-ahole airport.
* to provide a research tool to further develop the technology
* to develop the technology in-State for further application here and throughout the Pacific islands.

The basis for the design included the following requirements:

* Site at NELH
* Use OTEC deep-ocean cold water
* Produce a minimum of 30 KWe peak power
* Produce about 15 KWe average power (over an average year)
* Emphasize likelihood of success and reliability
* Use off-the-shelf equipment and technology as much as possible
* Operate as a firm power source
* Provide for research opportunities

The first step in developing the conceptual design was to identify the major components and size the facility.

The major components were identified to be:

Energy Pond
Energy Conversion System
Brine Supply
System Plumbing

B. Performance and Size

The required power output of the facility was given in the design contract. The first step in the conceptual design was to calculate performance and determine size from output estimates. A one-acre collecting area is used for trial calculations. The results of a more accurate calculation are given later based on the engineering design.

The conversion of sunlight to heat in the pond depends on the insolation, the clarity of the water and the thickness and stability of the upper convective and transition zones.

The amount of sunlight converted to stored heat in the pond depends on the amount of sunlight reaching the storage zone below the low-density surface layer. Estimates for other pond designs and experience range in the 10% - 25% range. The clarity and thickness of the upper layers controls the conversion of sunlight to stored heat. For Ke-ahole, a better than average performance is expected because: (1) there is very clear and clean water available, (2) it is a low-wind environment which would allow a thin (about one foot) upper layer to exist most of the time, and (3) little dirt is moved in the air to cloud the upper layer. For calculating a range of expected performances, values of 15% and 20% will be used. The insolation at the site is high but no long-term measurements exist. At similar sites, over 500 cal/cm^2/day occurs. Certainly, no fewer than 425 cal/cm^2/day occurs at Ke-ahole Point on the long term average (see Chapter IV). Thus a one-acre area (3.9 x 10^7 cm^2) would collect and store solar radiation as follows:

500 Cal/cm^2/day x 3.9 x 10^7 cm x 0.20 = 3.9 x 10^9 Cal/day--maximum
425 Cal/cm^2/day x 3.9 x 10^7 cm x 0.15 = 2.5 x 10^9 cal/day--minimum

or

3.9 x 10^9 Cal/day = 1.56 x 10^7 BTU/day = 4556 KWH$_t$/day--maximum
2.5 x 10^9 Cal/day = 1.00 x 10^7 BTU/day = 2921 KWH$_t$/day--minimum

Converting heat into shaft power is done by using a heat engine such as a Rankine cycle engine. The shaft power is then used to drive a generator to produce electricity. The conversion efficiency for the engine depends on the water temperature difference available. For the Ke-ahole site, the cool water would come either from the ocean or pond surface water, slightly cooled by evaporation to about 25 degrees C, or from the OTEC deep ocean cold water at about 6 to 12 degrees C (at the engine); the conservative number 12 degrees C will be assumed here.

The temperature of the hot brine is critical in calculating energy conversion efficiency. Operating temperatures of 85 degrees to 95 degrees C are calculated and experienced for other installations. Brine temperatures of 108 degress C (boiling temperature of 20% brine at pond bottom pressures) have been achieved in experimental ponds. A higher than normal temperature can be expected for the operating Ke-ahole pond. For purposes of estimating here the range of values of 85 degrees and 95 degrees C will be used.

The theoretical maximum conversion efficiency (e) (ideal Carnot engine) is

$$e_c = \frac{Tmax - Tmin}{Tmax}$$

(T must be in absolute of Kelvin degrees,
C degree + 273 degrees = degrees K)

$$e_c = \frac{368 - 285}{368} = 0.226 \text{ -- maximum}$$

$$e_c = \frac{358 - 285}{358} = 0.203 \text{ -- minimum}$$

Two commercial systems for converting heat to shaft power at these temperatures claim 67% and 70% of Carnot efficiency. Thus, the possible conversion efficiency to shaft power at the Ke-ahole pond should range as follows:

$0.226 \times 0.70 = 0.158$ -- maximum
$0.203 \times 0.67 = 0.136$ -- minimum

Conversion of shaft horsepower to electricity by a generator is about 87% - 94% efficient for three-phase generators running near peak output, here we assume 90% as an average. Thus, the efficiency of converting the hot water to electricity at the Ke-ahole site should range as follows:

$0.158 \times 0.90 = 0.142$ or 14.2% -- maximum
$0.136 \times 0.90 = 0.122$ or 12.2% -- minimum

The electricity that could be produced on the average using a one-acre collecting area with this system during a full year of operation ranges as follows:

4556 KWHt/day x 0.142 = 646 KWHe/day -- maximum
2921 KWHt/day x 0.122 = 356 KWHe/day -- minimum

The most likely performance is estimated to be near the 500 KWHe/day which is equivalent to a firm or baseload average generating capacity of:

27 KW/acre -- maximum
15 KW/acre -- minimum
23 KW/acre -- most likely

This is base load or firm power which can be drawn at any rate which does not exceed the generator capacity, up to about five-times baseload rate (of course for 1/5 the time period). Also, the load can be varied from day to day as long as, over the long term (weeks to months), the average load does not exceed the baseload rating.

There would be some seasonal variation to the base power producing capability of the pond due to long-term weather and sun angle changes. At the Ke-ahole site, this seasonal variation would be about 20% from the mean power output capability calculated above. A more detailed calculation could be performed to show precise weekly performance expected using environmental data, but this should not alter the average performance figures given here.

There will be some energy requirements to operate the pond (pumps mainly). From designs performed for other sites, this parasitic power demand is estimated to be between 10% and 20% of the gross power produced.

Thus a pond with a one-acre collecting area at Ke-ahole should more than meet the design power requirements.

C. The Pond Concept

A square-shaped pond concept was chosen for efficiency, ease of construction, and lower cost.

A pond with 1.4 acre surface area, 1.2 acre collecting and storage area and one-acre bottom was chosen as the baseline design because it is the largest pond that makes sense to achieve the project objectives. If cost or other consideration dictate, a smaller facility could be build from the same design and still meet the design power output requirements. With this in mind, the specifications and costs for a smaller, minimum plant, (a surface area of 0.81 acres, a collection area of 0.64 acres and with a bottom area of 0.5 acres).

The pond should be constructed above ground because it probably will be cheaper than a dug pond at this site and because the water table is only 12 feet below the surface. Water below the pond can carry away heat. The temperature profiles for several operating ponds are shown in Figures VII-1,2. The material below the pond also acts as an energy storage zone. Because the material below this pond (basalt) has very low thermal conductivity, serious heat loss is not expected.

An artificial liner will be needed to seal the pond and prevent brine loss. A wave supression system may be needed for the occassional heavy storm. The pond would be about 12 feet deep with 10 feet of brine and water structured to have about one foot or surface zone, four feet of gradient zone and five feet of storage zone. This follows "standard" pond design.

D. The Power Plant

Two, 15 KWe Rankine-cycle-engine-generator sets are suggested for this application. This provides efficient power generation at the base-load design level. The second generator would be operated when demand requires. This arrangement also provides redundancy for periods of maintenance or breakdown.

Turbine-generator sets for this application can be purchased as a stock item (90-day delivery). However, newer and more efficient designs are continually being developed. The specific unit used will be chosen during the engineerng design phase.

E. Salt Supply

Salt can be purchased to make brine or brine can be made locally by evaporating sea water. Approximately 2000 tons of salt or about 7-acre ft. of brine (about 20%) are needed for the baseline facility. In addition, some brine make-up facility will be needed to replace salt diffusing throught the gradient zone into the surface work water.

Initial cost estimates for salt purchase ran \$100/ton or higher. Thus there is an economic argument for making brine locally. The high net evaporation rate at the site enahnces this argument.

A solar evaporation brine production facility is proposed. This pond

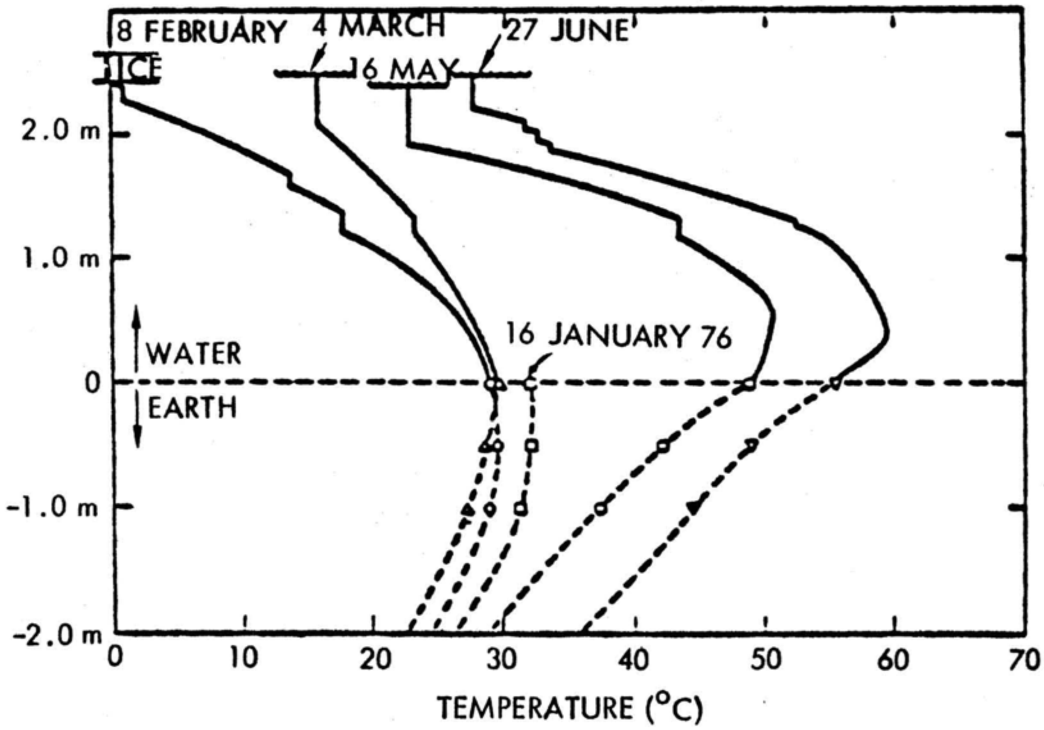


Figure VII-1.
Temperature Profile for the Farm Science Review Pond.
Source: Lin, 1982, after Nielsen, 1976.

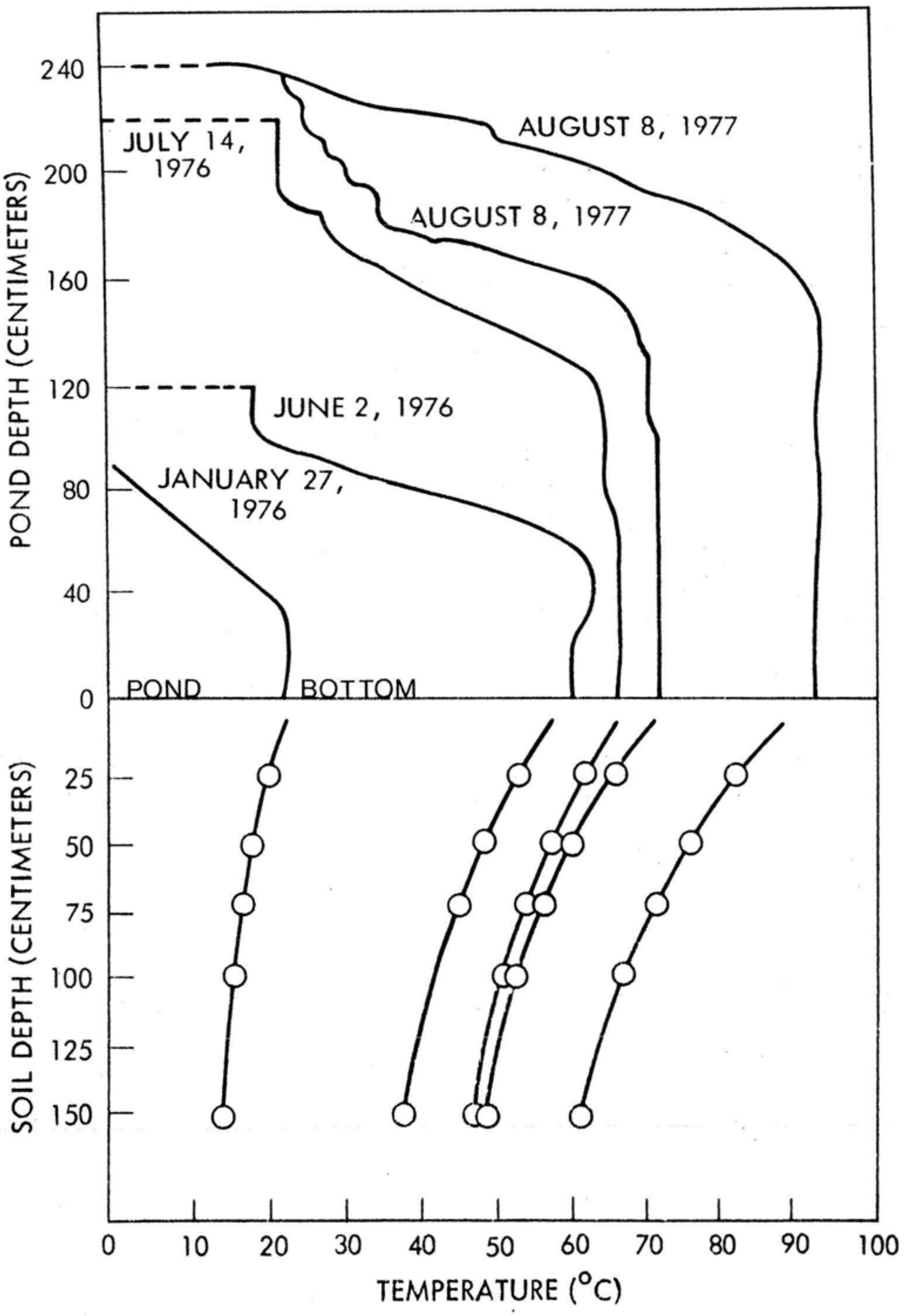


Figure VII-2.

Temperature Profiles for the UNM Pond

Source: Lin, 1982, after Zangrando, 1979.

for the baseline design would be two to four acres in area (or one to two acres for the minimum design), divided into section and be shallow (a few feet deep). Sea water would be evaporated to concentrated brine using traditional techniques. Evaporation enhancement techniques might also be used to increase the production.

The production rate for brine at the Ke-ahole site could be calculated if the evaporation rate were known (see Chapter XII), and assuming open sea water, measured at 3.4 to 3.6 percent salt, is used. To charge the solar pond about 20 percent brine is needed. This means a maximum concentration factor of about 6 times seawater.

Actual measurement at similar sites in Hawaii suggest an evaporation of about 90 inches net per year.

Evaporation is rather sensitively dependent on the temperature of the water and air movement over the water so that local conditions and the evaporation facility design can play a major role in affecting the rate of evaporation. Also, rain at Ke-ahole tends to be concentrated in certain seasons so that the annual amount of brine production might actually be increased by not operating during certain times.

All this suggests that the actual net annual evaporation experienced in a passive brine production facility properly designed at Ke-ahole could be greater than 90 inch/yr.

The amount of 20% brine which could be made in a one-acre evaporation pond for net evaporation rates of 90 inch/yr is about 0.53 million gallons.

The solar pond could begin operation at a reduced output with about 5 feet of brine and slowly be brought to full depth while some power is produced. To begin power production for a once-acre pond, 1.6 million gallons (6 million liters) of 20 percent brine is required. Full operation would require an additional 2 feet of brine.

The time required to produce enough brine to begin warm up of the solar pond assuming 90 inch/yr evaporation and a three-acre evaporation area is about one year. It would take another 4 months to produce enough brine to have a fully operating pond. This is probably acceptable if the salt production begins early in the construction phase.

Active methods of enhancing evaporation (such as spraying) could also be employed with some power consumption. Perhaps a factor of five improvement in efficiency could be gained this way. Thus a two-acre evaporation area could perhaps produce all the 20 percent brine necessary to fully charge the one acre pond in one year, using spraying.

The trade-off between salt production facility construction cost, area used, time to power production, extra power consumed and salt purchasing would be made in a detailed design study. The recommendation at this point, considering what is known about the site and the possible follow-up project objectives and also allowing some contingency, is to prepare a two- to four-acre evaporation area and look closely at the possibility of enhancing evaporation, perhaps by spraying.

After the first solar pond is fully charged, the salt production facility could be used to produce make-up brine to charge other ponds at Ke-ahole very cheaply.

F. Facility Site

Almost the entire area inside the NELH boundary is covered with lava flows. The material has the advantage of being a good thermal insulator and the disadvantage of being difficult to work and therfore expensive to build on. Soil conditions had little impact on where to locate the site.

In order to maximize the energy output of the facility it is necessary to minimize the temperature rise in the OTEC cold water supply line. Thus the shortest possible run is desireable. With this in mind, three locations were considered: Site #1, adjacent to the northeast boundary of NELH; Site #2, east of the access road and adjacent to NELH; and Site #3, west of the road and adjacent to NELH.

Inspection of the sites revealed that Site #1 is somewhat lower than #2 or #3 and has pockets of brackish water indicating underground streams which would tend to lower the insulating properties of the soil and thus increase the thermal loss through the bottom of the pond.

Site #2 and 3 are comparable in terms of soil properties, but #2 requires OTEC pipe runs 200-300 feet (30%) longer than #1, for this reason #1 was selected.

G. Facility Layout

The size, location and arrangement of the major facilities are shown in Figure VII-3 for the baseline design.

H. Pond/Power Plant Function

The flow diagram for this facility is shown in Figure VII-4. Hot brine is pumped from the pond bottom layer to the heat exchangers. A working fluid (freon, ammonia, etc.) in a closed cycle is vaporized by the hot water, and, as it expands, it drives a turbine which drives a generator. The working fluid vapor is then condensed back to a liquid using the OTEC deep ocean cold water and is reused.

The pond surface water will evaporate slowly and must be replenished. Water from rains or sea water can be used. This also helps remove dirt which may settle on the pond. During periods of heavy rainfall excess fresh water will build up on the pond surface because it is less dense than the pond salt water. This excess fresh water would be drained off automatically.

The salt ions will slowly diffuse upward into the fresher upper layer. To maintain the gradient, the upper zone is flushed (involving removal) and the storage zone is replenished (with stronger salt solution). The gradient zone stratigraphy will be further maintained by injecting brine at strategic places using a gradient maintenance nozzle manifold. Brine is made initially in the brine production facility and pumped to the brine make-up area for filtering and creating the proper concentration and then to the pond. After the pond is fully charged, no additional new brine should be needed unless there is leakage. The brine withdrawn from the pond for gradient maintenance would be reconcentrated by evaporation and returned to the make-up area.

I. Brine Treatment

Scaling and corrosion problems would have to be evaluated carefully in a detailed engineering design phase. They are not expected, however, to present serious difficulties at this site. Precipitation of scale-forming salts, if present in the brine, would occur in the brine storage pond, the evaporation pond or the solar pond, where they would not cause serious difficulties, and not on the heat exchanger surfaces. Also, concentrated brine--because of its very low oxygen solubility--has been found to be much less corrosive than ordinary sea water at the temperature of SPPP operation (90-95 degrees C). Nevertheless, saturated brine would be run thrugh the heat exchanger and a temperature drop would occur. Thus, precipitaton of unwanted salts could occur and this potential problem must be guarded against.

The brine collection and storage ponds and the evaporation ponds would serve also as settling ponds and help in the clarification of the brine if needed at all. Additional filtration may be required and residues of organic matter may have to be destroyed by weak (much weaker than normal swimming pool treatments) chlorination or copper sulface solution. This treated water would not be returned to the environment, except by catastrophic failure of the pond, for no water would leave this operating pond system except by evaporation.

J. Density Gradient Protection and Control

Solar salt-gradient ponds have proven to be very stable and do not mix easily even under unusual conditions such as rowing a boat across the surface. However, the more stable the gradient, the more efficient the pond, so that some precautions are wise. Especially important is maintaining the surface low-density layer as thin as possible to reduce sunlight absorption in this upper, convecting layer.

1) Factors Affecting the Density Gradient

The salt-induced density gradient produced when the pond is filled must be maintained during its operation. The upper layer thickness should be kept at a minimum and the interface between the mixed bottom storage layer and the non-convective zone should be maintained at its planned level. The formation of convective layers within the non-convective zone should also be prevented so that the heat insulation capability obtained by the non-convective zone is not reduced.

The main factors which could endanger the steady state of the density gradient in the non-convective zone are: (a) the molecular diffusion of salt from the bottom layer upwards; (b) evaporation from the pond surface; and (c) mixing of the pond by wind waves.

Other factors such as deviation for planned operation procedures although less important, may also contribute to some mixing of the pond. In order to protect the established density gradient and correct deviations from this gradient, the solar pond design includes three separate means for density gradient control. Two of these are designed to protect the planned density gradient from the varius mixing effects and the third is designed to correct deviations which have not been overcome by the first two.

2) Protection from the Effects of Ion Diffusion and Evaporation

A simple system is provided for maintaining the density gradient. The slow (0.1mm/day) ion diffusion tends to bring about a uniform salt concentration throughout the pond's depth. This system also prevents the increase of the natural evaporation or wave-action mixing. A number of methods have been developed for this purpose the simplest of which is the method of "salt addition and flushing." In this method, salt is added to the bottom layer in the quantities required to make up for the salt diffusing upwards. Salt is usually added in the form of brine which is more concentrated than the bottom layer. The salt ions diffusing upwards to the surface layer are continuously washed away by water which is less saline than the surface layer. The salt in the wash water is recovered by evaporation in the brine production facility.

The diffusion flux of salt ions upwards is proportional to the concentration gradient and to its diffusion coefficient, which varies with temperature and concentration. The diffusion flux for sodium chloride brine could be approximately 0.0123 lbs/ft /day or 0.1 mm/day change in the layer positions.

3) Protection Against Mixing by Wind and Waves

A wave diffuser system can be installed in a solar pond for protection of the density gradient from mixing by the action of wind and waves. Wind mixing can be limited by installing special floating nets on the surface of the pond. The Ke-ahole pond is small and in a low-wind zone so that wave dissipators are probably not needed. A simple system could be installed at low cost to guard against mixing during an unusual storm.

This wind protection system would keep the pond sufficiently undisturbed for any recorded wind conditions prevailing at Ke-ahole. This system is in use on the Israel ponds and is said to be very effective, even in winds of 100 miles per hour.

4) Repair of Deviations in the Density Gradient

If for some reason the gradient is disturbed a gradient control device would be used to repair such deviations.

This unit would be operating during the inital stratification build-up in the pond and the early utilization of the solar pond for power generation. After full power is obtained, however, they would be operated, only infrequently (weekly to monthly).

5) Support Facility

There would be a need for some covered building space to house the turbine-generators and other equipment and for maintenance and storage.

6) Plumbing

Pumps and pipes are required to implement the flow diagram. These would be electric pumps (with non-corrosive parts) and PVC pipe. Both are standard commercial items. The pumps would be run using surplus power from the SPOTEC facility. This parasitic power need is considered in the performance and cost calculations.

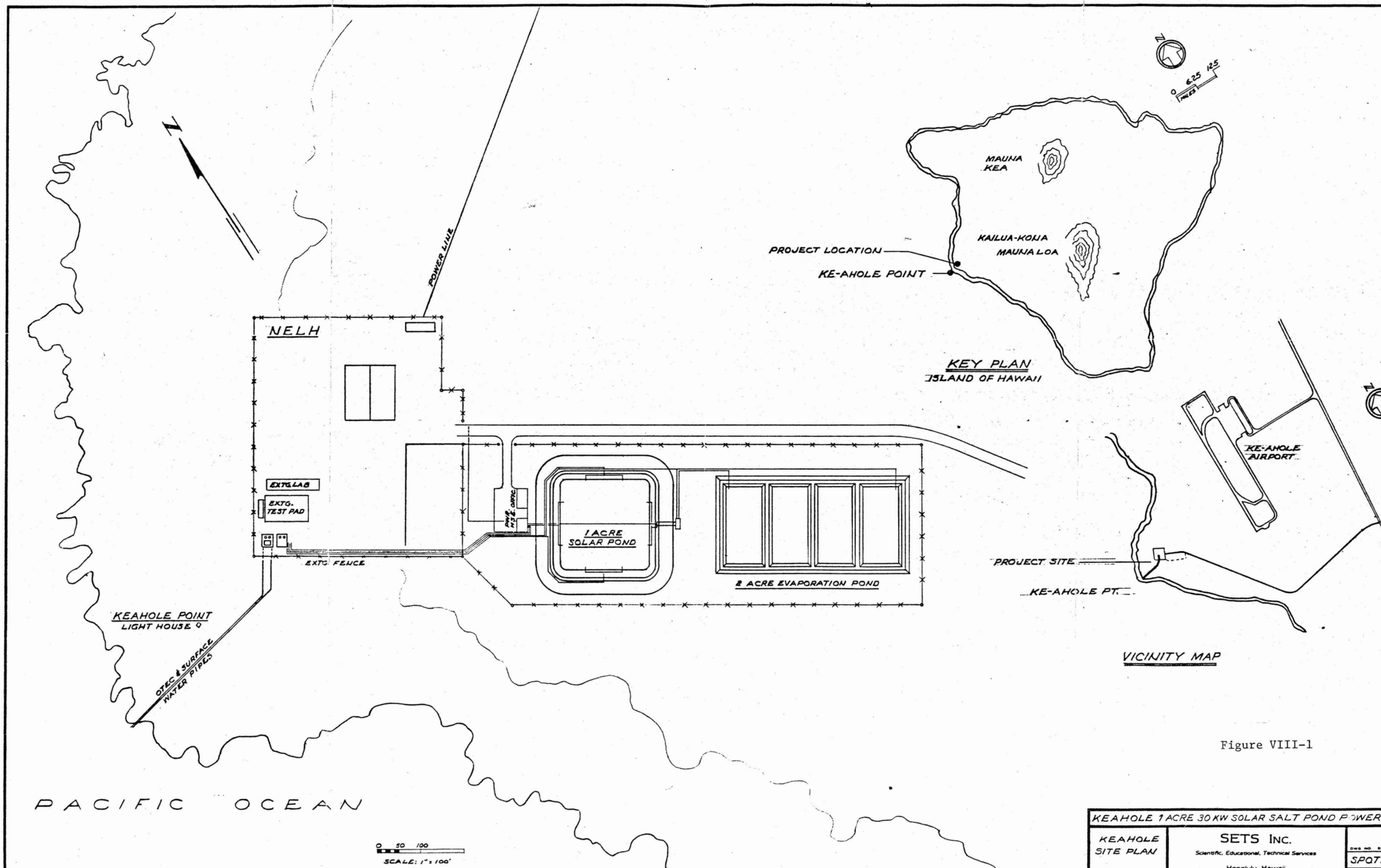


Figure VIII-1

VIII. ENGINEERING DESIGN OF THE 15/30 KWe SPOTEC POWER PLANT

As in the conceptual design, the engineering design is done for the 1.42-acre surface area, 1.2-acre collecting area, and 1-acre bottom area pond as the largest facility possible which makes sense given the project objectives. The facility could be scaled down, with very little engineering and drafting work, to the minimum facility (0.81-acre surface area, 0.64-acre collection area, and 0.50-acre bottom area) which meets the power output specification if costs or other considerations dictate.

A. System Layout on Site

The general layout of the ponds as shown on drawing number SPOTEC 1 (Figure VIII-1) follows closely the conceptual design layout. The orientation of the pond is governed by the desire to obtain the shortest length of fetch of the wind across the surface in order to minimize the wave action. The access road to NELH is perpendicular to the prevailing wind at Ke-ahole Point so the alignment along the road is proper and practical. The specific locations of the pond on the site were determined by the civil engineer and resulted in a minimum amount of site work

The evaporation pond is placed at a sufficient distance from the road that no brine mist of any consequence is expected to reach the road during the spraying operation under normal wind conditions.

The energy conversion equipment is placed on the side of the power pond which is the closest to the OTEC supply to minimize warm-up of the cold water. The equipment is placed on a concrete pad located on a graded platform which has room for an office/storage building, an equipment staging area and parking. The gradient and brine make-up equipment is located on a concrete pad between the power-pond and the evaporation pond in the vicinity of the hot brine return line.

B. Detailed Basic Specifications

1) Baseline Design

Square Bottom Area:	43,560 sq.ft. or 1 acre
Berm Height:	12 ft.
Berm Slope:	Interior 1 : 1 1/2 or 1:2 Exterior 1 : 3 or 1:2
Path Width	2 ft. (Top of Berm)
Length of Exterior Side	319 ft.
Total Area	101,576 sq.ft. or 2.33 acres
Material Required for Embankments and Cushion Fill	20,000 cu.yd.
Liner Required	65,688 sq.ft.

Water & Brine

Surface Area		56,983 sq.ft.
Surface Zone	1' ~	56,263 cu.ft.
Interface		55,559 sq.ft.
Gradient Zone	4' ~	197,510 cu.ft.
Storage Zone	5' ~	233,735 cu.ft.

Salt Content

Surface Zone	1.59 lbs/CF ~ 3.5% By Weight
Gradient Zone	Varies with Height From 22% to 3.5%
Storage Zone	13.75 lbs/CF ~ 22% By Weight

Salt Required

Gradient Zone	679 tons
Storage Zone	1,606 tons

Design Insolation (Monthly period) — Predicted Max. Output for (10')

Q	Average = 484 cal/cm /dy	=	22 KW and 29 KW w. OTEC
Q	Maximum = 731 cal/cm /dy	=	38 KW and 47 KW w. OTEC
Q	Minimum = 214 cal/cm /dy	=	11 KW and 14 KW w. OTEC

Assumed Efficiencies Collector = 21%, conversion = 12%
Overall = 2.5%

Extreme Power Flow Rates

Summer:	Hot Brine, 22% salt, 95 degrees C @	230 GPM
Winter:	Hot Brine, 22% salt, 95 degrees C @	86 GPM
Cold OTEC Seawater	3.5% salt, 12 degrees C @	200 GPM

Surface Evaporation

Average:	90"/year	~ 49 cu.ft./hr. =	6 GPM
Maximum:	136"/year	~ 74 cu.ft./hr. =	9 GPM

Salt Migration

Required 22% Brine for Reinsertion 425 gal/day

Wash Water Requirements

Summer	Wash In	30,500 gal/day	21 GPM
Summer	Wash Out	16,900 gal/day	12 GPM
Winter	Wash In	11,250 gal/day	8 GPM

Winter	Wash Out	7,200 gal/day	5 GPM

Energy Conversion Equipment

2 15 KVA nominal	SPS-ORC units with 100mm expander and 480 V generator.
Working Fluid	R-114
Nominal Pumping Rate	Hot Brine , 115 GPM for each unit with T of 5 degrees C.
	Cold OTEC , 91 GPM for each unit with T of 5 degrees C.

Unit Combination will operate with 70 GPM and with 250 GPM.

1 unit approximate size	9' x 4' x 4'
weight	4,200 lbs.

2) Minimum Design

Square Bottom Area:	21,780 sq.ft. or 1/2 acre
Embankment Height:	12 ft.
Embankment Slope:	Interior 1 : 2
	Exterior 1 : 2
Path Width	2 ft. (Top of Berm)
Length of Exterior Side	248 ft.
Total Area	61,306 sq.ft. or 1.40 acres
Material Required for Embankments and Cushion Fill	137,460 cu.yd.
Liner Required	40,000 sq.ft.

Water & Brine

Surface Area	1.31 acres	38,260 sq.ft.
Surface Zone	1' ~	37,481 cu.ft.
Interface		20,621 sq.ft.
Gradient Zone	4' ~	123,341 cu.ft.
Storage Zone	5' ~	124,188 cu.ft.

Salt Content

Surface Zone	1.59 lbs/CF ~ 3.5% By Weight
Gradient Zone	Varies with Height From 22% to 3.5%
Storage Zone	13.75 lbs/CF ~ 22% By Weight

Salt Required

Gradient Zone	424 tons
Storage Zone	858 tons

<u>Design Insolation</u> (Monthly period) — <u>Predicted Max. Output for (10')</u>

Q	Average = 484 cal/cm /dy	=	22 KW and 29 KW w. OTEC
Q	Maximum = 731 cal/cm /dy	=	38 KW and 47 KW w. OTEC
Q	Minimum = 214 cal/cm /dy	=	11 KW and 14 KW w. OTEC

Assumed Efficiencies   Collector = 21%, conversion = 12%
Overall = 2.5%

<u>Extreme Power Flow Rates</u>

Summer:	Hot Brine, 22% salt, 95 degrees C @	230 GPM
Winter:	Hot Brine, 22% salt, 95 degrees C @	86 GPM
Cold OTEC Seawater	3.5% salt, 12 degrees C @	200 GPM

<u>Surface Evaporation</u>

Average:	90"/year	~	49 cu.ft./hr. =	6 GPM
Maximum:	136"/year	~	74 cu.ft./hr. =	9 GPM

<u>Salt Migration</u>

Required 22% Brine for Reinsertion   158 gal/day

<u>Wash Water Requirements</u>

Summer	Wash In	20,479 gal/day	14 GPM
Summer	Wash Out	11,347 gal/day	8 GPM
Winter	Wash In	7,554 gal/day	5.5 GPM
Winter	Wash Out	4,839 gal/day	3.4 GPM

<u>Energy Conversion Equipment</u>

2   15 KVA nominal   SPS-ORC units with 100mm expander and 480 V generator.

Working Fluid   R-114

Nominal Pumping Rate   <u>Hot Brine</u> , 115 GPM for each unit with T of 5 degrees C.

<u>Cold OTEC</u> , 91 GPM for each unit with T of 5 degrees C.

Unit Combination will operate with 70 GPM and with 250 GPM.
1 unit approximate size   9' x 4' x 4'

weight 4,200 lbs.

C. Pond Design

The baseline power pond is square and its flat bottom is one acre. The bottom is surrounded by 12 feet high embankments with an internal scope of 1 1/2-1 and an external slope of 3-1. 2-1 slopes on both sides may be substituted as a cost saving measure. Compacted granular fill forms the bottom of the pond and the embankments. On top of the granular fill, on the pond bottom and internal faces of the embankment, is placed a 12-inch layer of cushion material. The purpose of this cushion layer is to ensure that the liner will not be punctured by rocks and other sharp objects. The liner is a 36-46 mils thick, plastic membrane which services as the water tight barrier. The liner is anchored in a gravel filled ditch on the top of the embankment. Limited vehicular traffic is possible on the exterior slope of the embankment. (See Figure VIII-2).

D. Site Grading and Pond Construction

1) Introduction

The primary considerations with respect to the grading and construction of this facility are to level the rough lava surface, construct the water containment embankments, and install a layer of material on which the impermeable liner will rest with minimum danger of tearing the liner due to irregularities in the subgrade. These tasks can be accomplished quite well as discussed below. It should be understood that some of the recommendations discussed below are generalized and are presented with the assumption that procedures will be evaluated and embellished during construction when, for example, the workability of the onsite basalt is better determined. Recommendations for site grading and for embankment compaction may be modified in the light of actual field experience to provide adequate structural characteristics in the most efficient manner. It is understood throughout this section that a site engineer or construction manager with suitable soils experience will be monitoring and inspecting construction activities.

Four factors dictate the approach to the construction of this facility as presented herein:

1) the site is characterized by abrupt relief on the order of 6 to 8 feet and roughness up to a few feet in height caused by lava flow features;

2) there is no soil at the site;

3) the use of an impermeable liner for the ponds allows some options in the approach to embankment design.

4) The onsite pahoehoe basalt is generally workable with heavy earthmoving equipment and site preparation activity utilizing such large equipment will have the benefit of disclosing any significant lava tubes below the surface so that remedial action can be taken.

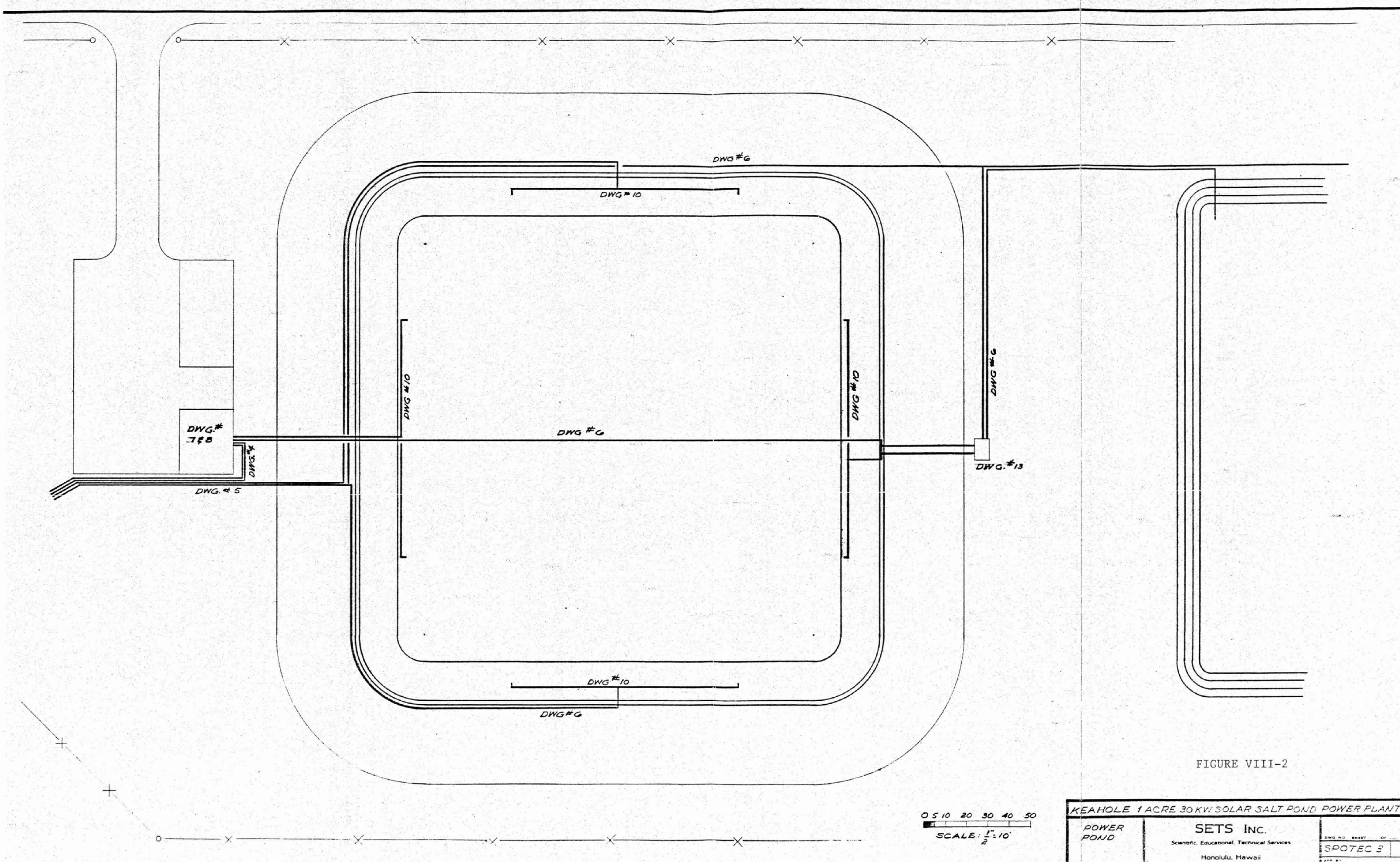


FIGURE VIII-2

The use of a conventional compacted earth embankment to contain the water of the power pond was examined initially. From an engineering standpoint this alternative is considered because it provides containment of the water in the event of a break in the liner. However, procurement of the suitable materials and the details of compaction necessary to provide a water "tight" embankment are quite costly. Additionally, the permeable nature of the surface on which the pond will be constructed eliminates the possibility of actually containing the water without relying on an impermeable liner. As a result of these factors, a design philosophy has been followed which entails:

* use of a cushion fill layer beneath the pond liner to protect it from the rough subgrade;

* use of an embankment design which depends on the liner for primary water containment and whose gradation is aimed at preventing loss of cushion material during compaction;

* a construction scheme which will depend on the onsite experience as determined by interaction between the contractor and soils engineer;

* compaction procedures specified both to compact the surface materials and to provide the proofrolling function.

In all cases, proofrolling and compaction should be observed and verified by the onsite soils engineer or construction manager.

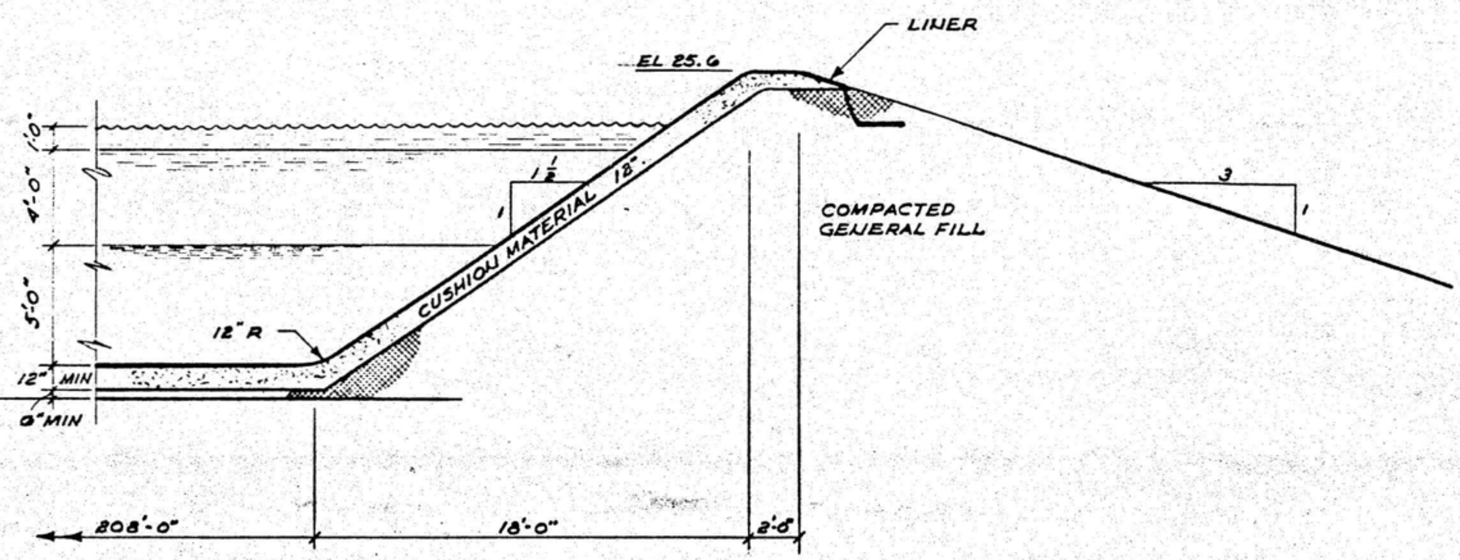
1) Embankment Configuration

The embankment configuration is shown on the Embankment Cross Section (Figure VIII-3). This section shows a 1.5:1 (horizontal:vertical) slope on the inside of the pond embankment and a 3:1 slope on the outside. The 1.5:1 slope was designated for pond efficiency considerations. From a construction standpoint, particularly liner cushion emplacement, a flatter slope may be desirable. If, during bidding and construction, it is determined that flatter slopes can be accommodated, 2:1 slopes both inside and outside, constructed in the manner outlined below, would be suitable. This is shown as an alternate on Figure VIII-3.

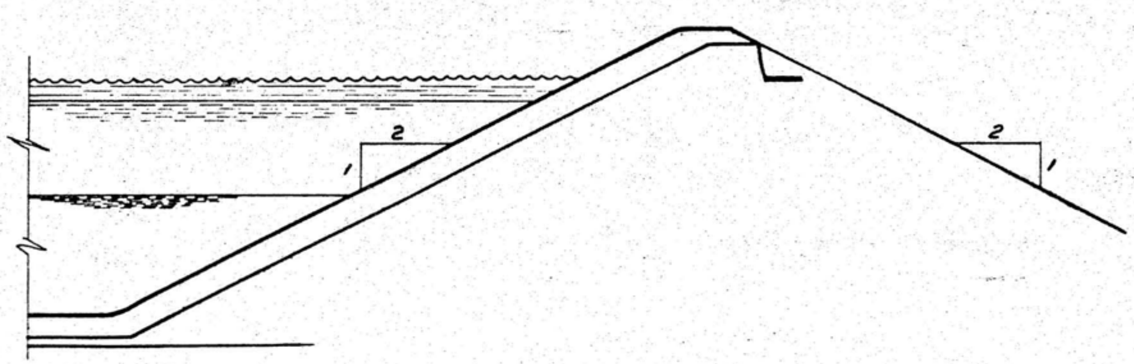
2) Site Preparation

Prior to fill placement, depressions and holes should be filled with onsite material not exceeding 12 inches in size in order to achieve effective filling of these features. Compaction of this material should be achieved by 4 to 5 passes with heavy bulldozer weighing at least 35 tons (D8H) with maximum 12" (loose thickness) lifts. Some experimentation may be necessary during the early stages of this work to identify the best compaction procedure. In special cases, as determined by the engineer, rocks larger than 12 inches may be used to fill holes and crevices.

At the initiation of this grading, proofrolling of the entire site (power pond and salt production ponds areas) should be carried out by large



EMBANKMENT CROSS SECTION



ALTERNATIVE CROSS SECTION

NOTES

LINER, HYPALON INDUSTRIAL GRADE MEMBRANE LINING, 36 MIL THICKNESS WITH A POLYESTER SCRIM REINFORCEMENT OF 6X6-1000 d. LINER TO BE FURNISHED IN 3 FACTORY FABRICATED PANELS.

IT IS IMPERATIVE THAT THE POND LINER NOT BE PUNCTURED BY RESTING ON SHARP OBJECTS OR BE RUPTURED BY STRESSES CAUSED BY SETTLING OF THE FOUNDATION LAYERS. THE GRAVEL AND CUSHION LAYERS AS SHOWN ARE CONSIDERED SAFE. HOWEVER THE CONTRACTOR IS INVITED TO PROPOSE ALTERNATE THICKNESSES FOR SUPPORT LAYERS BASED ON HIS MATERIALS.

AS SHOWN THE QUANTITIES ARE:
GENERAL FILL 16356 CU. YRDS
CUSHION LAYER 2389 CU. YRDS

ALTERNATIVE CROSS SECTION QUANTITIES ARE:
GENERAL FILL 14971 CU. YARDS
CUSHION LAYER 2591 CU. YARDS

FIGURE VIII-3

KEAHOLE 1 ACRE 30 KW SOLAR SALT POND POWER PLANT		
EMBANKMENT	SETS Inc. Scientific, Educational, Technical Services Honolulu, Hawaii	DWG NO SHEET OF SPOTEC 19

bulldozer (D8H or larger) to disclose near surface lava tubes which might collapse under the weight of the proposed facility. The proofrolling procedure should provide enough passes over the site area to impose loads on the surface which are larger than the proposed construction. Proofrolling in the power pond area should be such that each square foot of the surface receives at least one pass of actual tread contact. For the salt pond production areas, proofrolling with a simple overlapping plattern should be adequate. Voids disclosed should be examined by the site engineer, and widened (under his direction) as necessary to disclose their extent. These voids should then be filled with rock as discussed above. Jackhammer drill probing may be necessary to fully disclose the extent of lava tubes in suspect areas. Particular attention should be given to areas beneath the power pond and its embankments where imposed loads will be large. The services of an engineering geologist with volcanological background will be useful, at the early stages of proofrolling, to identify likely sites of lava tubes.

Inside embankment areas (discussed below) and all surfaces of the power pond should be brought to grade with a minimum compacted thickness of 6 inches of 'general fill' overlain by 12 inches (compacted thickness) of 'cushion material'. (Specifications for these fill designations are given below.)

The embankment should be constructed as indicated on the Typical section (Figure VIII-3). Compaction procedures are discussed in the Fill Materials section, below. The outside slope of 3:1 (horizontal:vertical) may be modified locally for providing an access roadway to the top of the embankment. The width of the general fill and cushion fill to be placed on the 1.5:1 (horizontal:vertical) inner slope are primarily dependent on the equipment utilized for compaction of these materals. A minimum effective vertical thickness of 12 inches (compacted thickness) is recommended for cushion material for such slopes.

In the area of the salt production ponds, the general fill should have a minimum compacted thickness of 6 inches and the 'cushion material' should be a minimum of 6 inches.

3) Fill Materials

On the pond bottom, the general fill is designated primarily to provide gradation between the cushion layer and the basalt under the pond area. This material will also comprise the main portion of the embankment. The general fill should be non-expansive mineral material reasonably well graded from coarse to fine to enable efficient compaction. General size gradation should fall in the following limits:

100% smaller than 12-inches maximum dimension;
50-90% passing the 3-inch sieve; and
10-30% passing the 3/4-inch sieve; subject to approval by the construction manager.

This material should be compacted to 90% of the maximum dry density as determined by AASHO test designation T-180D. Compaction of this material should be accomplished by a minimum of 6 passes with a vibratory roller generating at least 60,000 lb. dynamic force. Lift thickness should not exceed 12 inches (compacted thickness). At the top of the general fill, under the cushion material, no individual rock should protrude above the surface of the fill more than 2 inches in order to prevent 'hard spots' beneath the cushion and liner.

Cushion material is designated to protect the liner and as such is subject to any liner-specific specifications and should have the following general size characteristics:

100% passing the 1-inch sieve;
100-85% passing the 3/4-inch sieve; and
less than 20% passing the #200 sieve; subject to approval by the construction manager.

The cushion fill should be compacted in 6-inch (compacted thickness) lifts to 90% of the maximum dry density (AASHO T-180 D).

It may be useful to substitute a fabric liner, in lieu of the cushion and general fill layers, on embankment slopes where compaction may be difficult. Consideration should be given to this alternate at the time of bidding and contractors should provide samples of proposed fabric.

E. Energy Conversion Plant Design

The power conversion machines proposed for this project are designed and fabricated by SPS, Inc. of Miami, Florida.

The design is based on the organic rankine cycle and in this case the working fluid is Freon 114. The stainless steel boiler and condenser are mounted on a steel frame which also supports the screw expander and generator, the freon pump and all the required controls. The units are completely self contained and may be handled by a forklift. These 15 KV units measure approximately 4 x 4 x 8 feet and weigh about 2,600 lbs. Hot and cold water and electrical connections are the only items required in the field for the installation.

F. Plumbing System Design

1) Introduction

The handling of sea water and hot brine require special attention in terms of corrosion, salt migration and temperature. All the materials employed in the plumbing which comes in contact with sea water or brine are some kind of plastic; PVC, CPVC, polypropylene, fiberglass reinforced epoxy, etc. Cast iron pipe could be used for the hot brine, but the ease of handling of the fiberglass piping outweighs any cost advantage in the purchasing.

In general the plumbing can be divided into two categories, cold water piping and hot brine piping. For both categories the fluid pressures, and velocities are low in order to minimize the parasitic power losses.

PVC piping is suitable for all the cold water lines. Pipe and fittings are readily available and easy to work.

For the hot brine CPVC or fiberglass, reinforced epoxy is required. This design utilizes fiberglass reinforced epoxy pipes and fittings for the hot brine as the temperature rating is higher than for CPVC. Pipes and fittings are readily available and relatively easy to work.

2) Cold Water Piping

The cold water piping consists of two separate circuits, (1) sea water supply for pond surface washing, and brine makeup and evaporation pond feed, and (2) the OTEC supply and return.

The sea water supply is obtained from the NELH main water supply center at the maximum rate of 56 GPM. The routing goes from there to a booster pump and filter by the pond power house. On the pond embankment the line divides into the pond wash supply and the evaporation pond supply.

The pond wash supply line is routed near the top of the embankment to the diffusers. Connections for a deaereator and a biocide holding tank are located at the high point where the line crosses over the top of the embankment. The elevation of the diffusers is adjustable to allow for gross water level changes. Typically the diffusers will be located 6 inches below the surface of the pond.

The maximum anticipated evaporation rate will require a flow rate of 56 GPM for 9 hours per day to maintain the pond water level and flush debris and migrated salt out of the pond.

The pond wash collectors are located across the pond from the supply diffusers. Their elevation is adjustable to allow them to be placed just below the pond surface. A pump and a 3-way valve located on the embankment makes it possible to send the wash water either to the evaporation pond supply line or to the return line which terminates at the NELH return pond. Because of the upward salt migration in the pond water and because of evaporation of surface water the flush water salinity is increased, thus making it better suited for brine fabrication than ordinary sea water. It is anticipated that normal operation will route all the water to the evaporation pond.

The evaporation pond supply line follows the power pond and evaporation pond embankments and is terminated in the first evaporation pond cell. A branch is connected to the brine make-up facility.

3) OTEC Supply and Return Line

The cold OTEC water is obtained at the NELH main water supply center. The OTEC supply line is insulated to preserve the low temperature of the water. In the power house it is split into two parallel circuits through the energy conversion machine condensers. Pumps and filters are located ahead of the condensers. The return line is not insulated and returns the water to the NELH water center for further use. The maximum pumping rate is 200 GPM. Aside from the sand filter, no treatment of the water is required and since the condensors are made of stainless steel the only change in this water is a slight temperature increase. It is thus suitable for further use.

4) Hot Brine Circuit

Brine Extraction. The four brine collectors are fixed 12 inches from the top of the storage zone. Manifold piping brings the brine to a single pipe which is insulated above the water level and which has a deaereator and a primer valve at the high spot where it traverses the top of the embankment. In the power house it is split into two parallel circuits through the energy conversion machinery boilers. Pumps and filters are located ahead of the boilers. The return line is routed from the power house over the embankment across the bottom of the pond to the far side where it emerges to the top of the embankement before returning to the diffuser manifold on the bottom of the pond. At the top of this loop, it is provided with a deaereator and a connection to the brine make-up facility. The line is insulated when outside the pond water.

The major reason for routing the return line across the pond bottom is cost, however there is the additional benefit that heat losses are minimized thus increasing the overall pond efficiency. No particular maintenance problems with this submerged pipe are seen. Pumping air into the pipe will make it float for retrieval if ever required.

5) Brine Make-up and Gradient Maintenance

The brine make-up and gradient maintenance facility is located on a concrete platform between the power pond and the evaporation pond, close to the power pond.

The facility consists of two 600 gallon tanks for brine, one tank for biocide, a filter, and pumps. Sea water is supplied from the evaporation pond supply line and brine from the evaporation pond.

The brine make-up supply is delivered from the make-up tank to the hot brine return line, ahead of the deaereator where it loops out of the pond on the top of the embankment.

The gradient maintenance make-up tank is located adjacent to the brine make-up tank and is connected to the seawater and brine supply lines through metering valves. The metering valves will allow continuous water supply to the tank at pre-determined salinities. The tank is also connected to the biocide make-up tank. Pet cocks for sampling are provided. The equipment required for the introduction of the gradient water consists of a circular diffuser which is fed from the make-up tank through a 1" hose. The diffuser is secured to a movable anchor on the bottom of the pond which initially will be placed near the center of the pond. The elevation of the diffuser is controlled by a wire attached to a graduated winch on the embankment. When anomalies in the gradient curve occur they may be removed by a program of inserting brine of the proper salinity at the proper elevation in the gradient zone.

Wind borne debris and debris formed in the pond tends to settle at a level matching its specific gravity. By reversing the pumping direction the gradient diffuser may be utilized as a "vacuum" cleaner head. The stratification of the gradient zone is very well defined. The frequency with which repairs need to be made to the gradient zone is unknown but probably will be monthly.

G. Instrumentation Systems

1) Introduction

It is recommended that the solar pond facility have an instrument system in order to monitor the facility state and performance. The purposes of this system are: 1) to carry out basic maintenances, 2) to allow automation of operation and 3) to obtain data for research purposes. Only the first purpose is absolutely required, but considerable value of the facility would be lost if the research potential were not realized. Automation is a long-term important objective to reduce maintenance costs and advance the technology. An instrument system was designed and is present here to support all these purposes. A reduced system to support only basic maintenance is also given at the end of this chapter as a lower cost option. The instrument system will consist of an array of different kinds of sensors wired to a central mini-computer which will automatically sample the sensors and output the data on a digital storage medium and on hardcopy, and through a modem communication system. Maintenance of the solar pond and operation of the solar pond support system will be based on the software evaluation of the collected data. A detailed list of sensors and suggested manufacturers is also given.

The data obtained from the various sensors will also be used for the evaluation of pond performance. Measurements made over an extended period will indicate the ponds capability to collect and store heat. Some of these measurements are the amount of solar heat available to the pond, the heat losses through the gradient, and to the ground, the amount of heat extracted, and the state of the insulating salt-gradient region.

The measurements will be made to monitor the state and performance of the power conversion system probably using the instrument package supplied with the power conversion units but interfaced to the data acquisition system. The salt production facility will be monitored for state and performance and measurement also will be used to monitor the flow of water and brine to and from this pond, the power conversion system and the salt production facility. External environmental parameters such as insolation and wind would be monitored. The entire pond/plant could be totally automated and monitored from a distance using this instrument system, perhaps with small changes based on experience, if certain valves and mechanical motions were motorized.

The results and analysis of these data will help in the technological advancement of the solar pond as a heat collection and storage device. The dimensions and physical characteristics of the Ke-ahole solar pond are those of a "conventional" solar pond. Evaluation of its performance is therefore directly relevant to the science of solar ponds. In addition there are several novel characteristics of the facility, such as OTEC which makes it of special scientific interest.

2) Instruments

The following information describes the type of sensors recommended in this design. Their location and placement are discussed in later sections.

The sensors suggested to measure the thermodynamic properties of the solar pond support system are the temperature sensor and the salt density meter. The temperature sensor recommended is a platinum/rhodium resistor (RTD) which produces a resistance change proportional to the temperature change. It is a reliable device which is small in size and easy to encapsulate. The salt density sensor is a conductivity probe that utilizes coupled inductors to measure the brine density. The conductivity, along with temperature compensation, is proportional to the brine specific gravity which is in turn proportional to brine density. This device comes from the supplier with a galvanometric meter for direct field reading of the inductive coil voltages and it has a protective cover over the probe.

Liquid sensor probes are necessary in order to monitor pond leaks and to electronically trigger the computer sensor sampling mechanism when executing an instrument vertical solar pond scan. There are two types of liquid sensors recommended. One is a single voltage change device to detect the solar pond surface, and the other is a bare copper wire grid (two crossed layers separated by a few inches of material) beneath the solar pond liner that begins to conduct when fluid is introduced between two grid wires. The location of this increased conductivity corresponds to the location of a pond leak. These both will offer analog input to the data acquisition system.

Meteorologic information will be supplied by a collection of analog sensors located near, but above, the pond surface, each interfaced through the computer. A pyrometer is recommended to measure the insolation; the computer will perform an integration to determine average values of insolation. The pyrometer will be capable of scanning the pond vertically to determine the light transmission qualities of the salt-gradient. Standard wind velocity, rainfall, barometic pressure, ambient temperature, and humidity sensors will be connected to the data acquisition system, and sampled on a regular basis. The dew point spread will be required for evaporation monitoring, therefore a wetbulb/drybulb thermometer will also be utilized.

The other sensors to be used are as follows: Flowmeters for measuring fluid velocities within pipes, and position indicators to determine the orientation of fluid inlets/outlets (i.e., evaporation pond, brine spray nozzles, diffusers, pump valves, etc.). The power output of the power production facility will be checked by computer at regular intervals. A turbidity meter will scan the pond and give an indication of brine clarity. A PH meter and brine sampling device consisting of a pump and a series of teflon tubes will also be used to analyze the brine quality.

3) Sensor Locations

Figure VIII-4 shows the location of the sensors used to monitor the solar pond and its support system. The table at the bottom of the figure gives the code for sensor/letter equivalence, and the letter in the drawing corresponds to sensor location. Figure VIII-5 shows the basic electrical wiring scheme along with sensor connections. The number of the sensors recommended its purpose, as well as the order in which they should be installed in the construction scheme, is as follows:

- 20 RTD temperature sensors located in the loose fill beneath the solar pond, used to measure heat flow out of the pond. This should be installed before the liner and sand pad installation.

- 20 RTD temperature sensors located in dense basalt

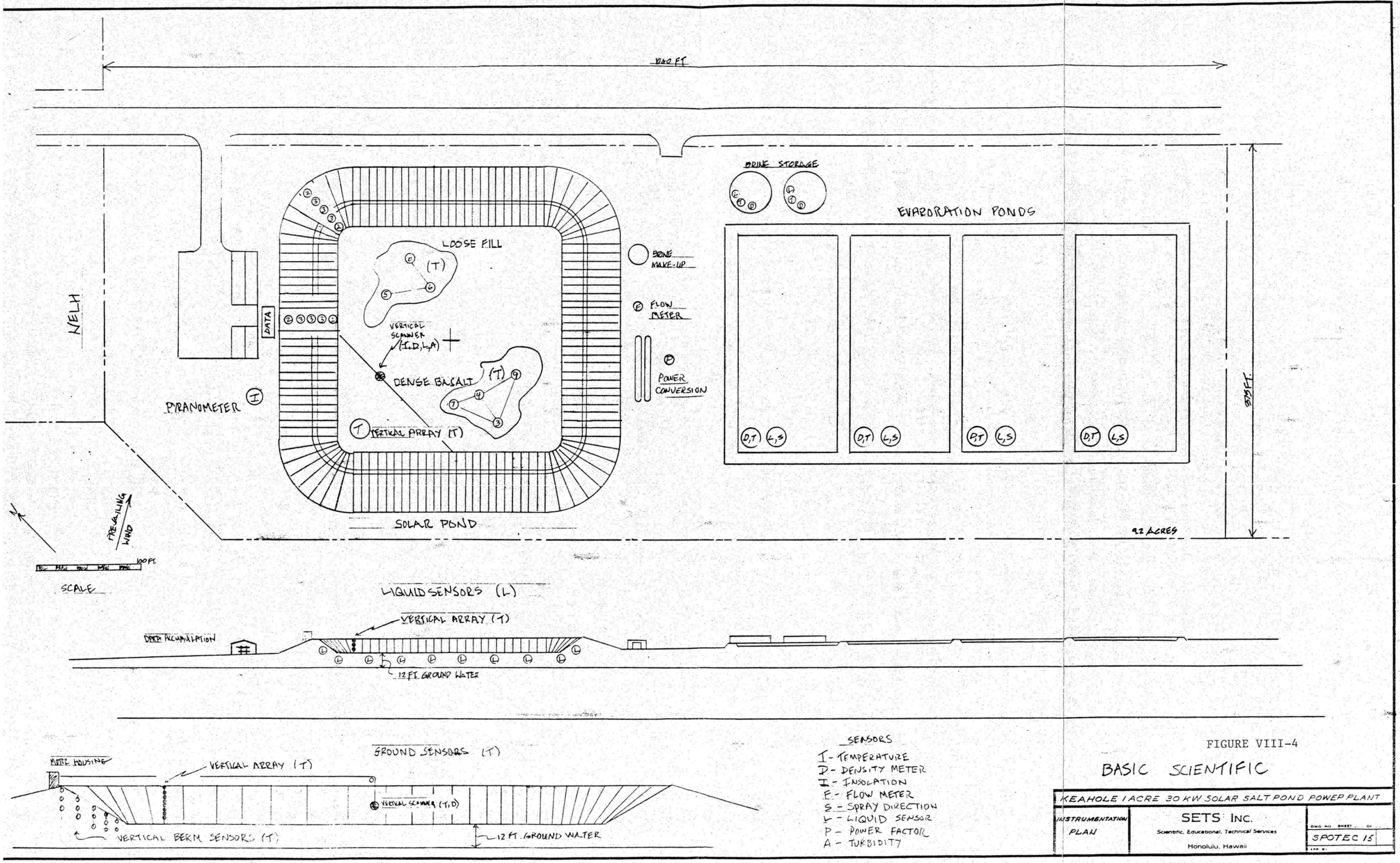


FIGURE VIII-4

BASIC SCIENTIFIC

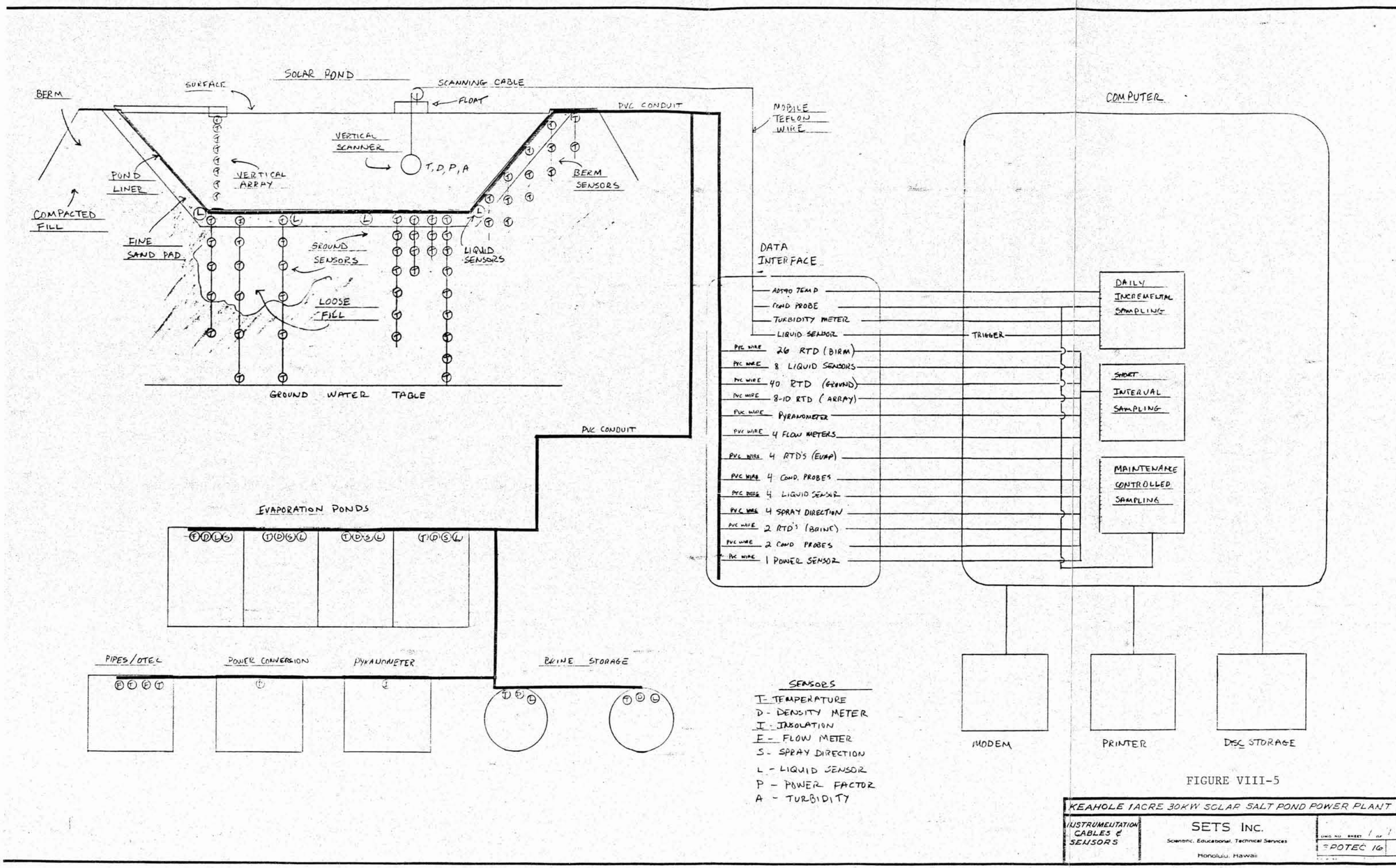


FIGURE VIII-5

beneath the pond for the same purpose and installed along with those above.

- 26 RTD temperature sensors located in the berm (corner and side) to measure heat flow out of the pond, installed before liner and sand pad installation. (Note: Sensors placed along expected isotherms.)

- 4 x 4 grid of copper wire placed in the sand pad, and also next to drain, to detect location of leaks in the solar pond. The grid consists of 4 wires placed equally and uniformly spaced parallel to two sides of the pond and between the sides. A second 4 wires should be placed orthogonally to the first 4 and separated vertically from them by a few inches.

- 6 RTD temperature sensors, one in each evaporation pond and brine storage tank installed along with the corresponding temperature sensors above, but after evaporation pond line installation.

- 6 density probes (conductivity meters). One in the solar pond, one in each evaporation pond and the brine storage tank, installed along with the corresponding temperature sensors.

- 6 liquid level sensors, one in each evaporation pond and the brine storage tank, installed along with corresponding temperature and density sensors.

- 2 flow meters attached to the brine inlet/outlet and diffuser pipe to measure fluid flow.

- 2 (RTD) temperature sensors located in the brine inlet/outlet and diffuser pipe to monitor fluid temperatures.

- 1 underwater-rated pyrometer to measure average daily insolation connected to a teflon wire capable of being attached to the vertical scanner for use in brine clarity determination.

- 1 RTD temperature sensor attached to the vertical scanner, and connected with teflon wire, to measure the temperature versus depth characteristics within the solar pond. This should be installed after the pond is filled.

- 1 density meter (conductivity probe) attached to the vertical scanner, protected from corrosion by a tygon tube, used to measure the salt-density versus depth characteristics within the solar pond, installed after pond fill.

- 5 spray nozzle/diffuser position sensors.

- 1 turbidity meter attached to the vertical scanner, connected by teflon wire, to measure brine clarity, installed after pond fill.

- 1 liquid level sensor attached to the vertical scanner, connected by teflon wire, used to trigger the sampling routine, installed after pond fill.

- 10-12 RTD temperature sensors placed vertically within solar pond to offer redundant data for temperature scan. Their segmentation is relative to the pond bottom. They should be installed after pond fill.

The recommended schedule for sensors installation during construction is given in Table VIII-1 in the Installation section.

4) Data Acquisition System

The Data Acquisition System (DAS) is shown in Figure VIII-5 and appears in the sensor location section. It consists of the electronic sensors, the interface, a central processing unit, the software to operate the system, and the peripheral devices used to display data and communicate with other computers. The DAS will have three primary monitoring functions, 1) daily incremental sampling which will include the pond vertical scan, 2) short interval sampling which will collect data from stationary points simultaneously, and 3) maintenance controlled sampling which will occur before and after maintenance has been performed.

The software to support this DAS is facility-specific and will require a specialized effort on the part of the construction project manager. There are however, solar pond software packages available that might be adapted at a reduced cost to fit the needs of the Ke-ahole DAS. See the cost analysis included in the budget.

5) Installation

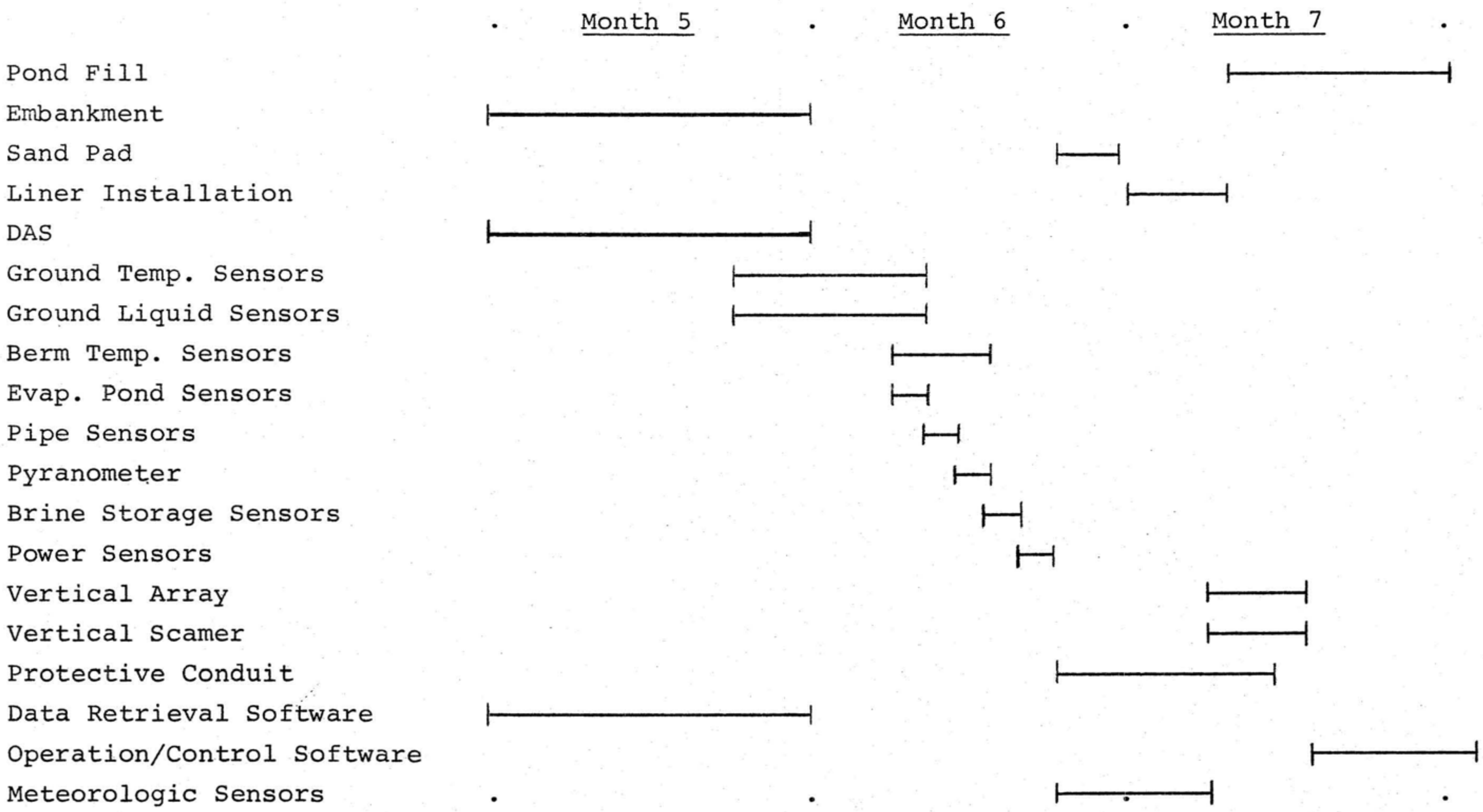
The installation of the instrument and system will occur in two phases during the construction. The installation of the DAS and computer programming can be performed independent of the other phases of the construction. The sensor installation schedule will be dependent on the construction schedule. Table VIII-1 shows the sequence for installation of the monitoring system and presents an approximate schedule.

Table VIII-1 shows the suggested schedule for the physical placement of sensors, cables, development of the DAS, the computer programming. Before completion of the embankment, the DAS and required data retrieval software should be complete. Following this, sensors and cables will be installed before the pond sand pad and liner installation. While this system is operating, the facility operation and control will begin. An estimate of labor costs also appears in the budget section.

Care must be taken when installing the liner to avoid the possibility

Table VIII-1.

Instrumentation and Monitoring System Installation Time Schedule.



of heavy equipment damage to the sensor cables. This should not be a problem if the cables are housed in PVC conduit and have been given sufficient slack to allow for any motion.

6) Operation

When the DAS is successfully retrieving data from the various sensors the process of data accumulation will begin. The computer will automatically sample the various sensors and store the data on magnetic files as well as in hard copy.

In the early periods of operation the instrumentation and monitoring system will require manual care, however, complete automation could be reached as soon as the calibration of sensors and the fine tuning of the pond maintenance equipment is complete.

7) Considerations and Options

There are two alternate instrumentation and monitoring systems, 1) the Basic Scientific, and 2) the Basic Maintenance. The latter differs only in that the sensors used to measure the parameters strictly for scientific analysis are eliminated. System 2) is the bare minimum necessary only to operate and maintain the solar pond facility.

8) Parts List and Cost

A list of parts and materials is given along with cost estimates for the two alternative systems: 1) basic scientific and 2) basic maintenance only. The basic scientific system includes the basic maintenance capability.

Basic Scientific:

Quantity	Item	Description	Price
1	Data Acquisition System	LSI-11	$10,000
1	Data Interface	Omega 100 channel	16,000
1	Printer/Plotter	DOT Matrix	500
1	Modem		500
1	Phone Line	36 mo. x 42$/mo. (+ $90 installation)	1,600
80	Temp. Sensors	RTD, Omega	2,400
18,600 ft.	Temp. Sensor Wire	4/3 lead stranded PVC	2,232
3	Temp. Sensors	AD590 Analog Devices	5
1	Temp. Sensor Circuit	Analog devices	100

7	Conductivity Probe	Inductive Type	10,500
1	Pressure Transducer	0-15 Psig w/25 ft. cable	500
2,400 ft.	Liquid Sensors	Copper uninsulated	120
2,100 ft.	Liquid Sensor Wire	PVC	252
3,000 ft.	Liquid Level Wire	PVC	150
1	Turbidity Meter	Bockel Inc.	500
500 ft.	Turbidity Meter Wire	Teflon	600
4	Flow Meters	Cahl Sci.	2,420
1	Pyrometer	Eppley Underwater	1,365
500 ft.	Pyrometer Wire	PVC	60
1	PH Meter	Model 55 Nestor, Hawaii Chem.	210
1	Multimeter	Beckman	130
1	Power Supply	0-30V DC	50
	Misc. Elec. Devices	Switcher, relays, capacitors, resistance, transformers	500
1	Analytical Scale	Dial-O-Gram	105
1	Water Pump	1-16 ft. height Self Priming	100
150 ft.	Sample Tubing	Tygon 1/4' ID	130
1	Hygrometer	Hawaii Science	25
150 ft.	Conductivity Probe Protective Tubing	Tygon 1 1/4" OD	370
300 ft.	Scanner Cable	S.S Plastic Coated	15
1	Synchronous Motor	Hurst 1 rpm 600 ozin torque	68
1	Hot Plate	0-100 degrees C	50
6	Beakers	100 ml	17
6	Weighing Flasks	45 ml	45

10 lb.	Sensor Potting Compound	Devcon H.S. Gray	150
1	Wind Speed Indicator	Handar	525
1	Wind Direction Indicator	Handar	400
1	Rain Gauge	Handar	450
1	Barometric Pressure Gauge	Handar	900
1	Wet Bulb/Dry Bulb Thermometer	Cahl Sci.	125
	Labor	Sensor, cable, DAS installation, 30 dys @100$/dy	3,000
	Labor	Data Retrieval software design, 15 dys @100$/dy	1,500
	Labor	SGSP operation and control automation software design, 15 dys @100$/dy.	1,500
	Miscellaneous	Aluminum, PVC, Plexiglass, Hardware, Solder, Tape Conduit, Air Quality Jars, etc.	1,000
		TOTAL	$61,169.00

Basic Maintenance:

Quantity	Item	Description	Price
1	Data Acquisition System	Apple	$ 3,000
1	Data Interface	Omega: 50 Channel	4,000
1	Printer/Plotter	Dot Matrix	500
1	Modem		500
1	Phone Line	36 mo. x 42$/mo. (+ $90 installation)	1,600

40	Temperature Sensors	RTD, Omega	1,200
5,000 ft.	Temperature Sensor Wire	4/3 lead, stranded PVC coated	600
7	Conductivity Probe	Inductive Balsbaugh	10,500
2,400 ft.	Liquid Sensors	Copper Insulated	120
2,100 ft.	Liquid Sensor Wire	PVC	252
3,000 ft.	Liquid Level Wire	PVC	150
1	Turbidity Meter	Bochel, Inc.	500
500 ft.	Turbidity Meter Wire	Teflon	600
2	Flow Meters	Cahl Scientific	1,210
1	Pyrometer	Eppley	1,300
500 ft.	Pyrometer Wire	PVC	60
300 ft.	Scanner Cable	Stainless steel, Plastic coated	15
1	Synchronous Motor	Hurst, 1 rpm, 600 ozxin torque	68
10 lbs.	Sensor Potting Compound	Devcon H.S. Gray	150
	Misc. Elec. Devices	Switches, relays, capacitors, resistors, transformer.	500
1	Hygrometer	Hawaii Science	25
1	Wind Speed Indicator	Handar	525
1	Wind Direction Indicator	Handar	400
1	Rain Gauge	Handar	450
1	Barometric Pressure	Handar	900
1	Wet Bulb/Drybulb Thermometer)	Cahl Inc.	125
	Labor	Sensor, cable, DAS installation, 30 dys @100$/dy	3,000

Labor	Data retrieval, software design 15 dys @100$/dy	1,500
Labor	SGSP operation and control automation software design 15 dys @100$/dy	1,500
Miscellaneous	Aluminum, PVC, Plexiglass, Hardware, Sealer, Tape, Conduit, Air Quality Jars, etc.	600
	TOTAL	$33,850.00

H. Pond Maintenance Facility

The salt gradient maintenance facility consists of the gradient make-up tank, a pump and the movable gradient diffuser unit. See Section F, item 5 for further description.

I. Support Facilities

The solar pond and evaporation pond facilities require minimal maintenance and service so consequently only minimal support facilities are proposed.

A 25 ft. x 30 ft. concrete pad is provided in the corner of the graded parking area near the center line of the power pond. This pad serves as a base for the energy conversion equipment, pumps, filters, electrical panels which all are weather proof and a weather proof cabinet for instrumentation terminals. It is presumed that a small general storage area, 250 sq. ft., can be identified at the existing NELH facilities.

The only major service operation is the periodic cleaning of the boilers and condensers. The simple handling equipment required can be borrowed from NELH or rented.

An inflatable stable boat is required for the servicing of in-pond equipment.

Figure VIII-6 depicts a detailed layout of a complete support facility. This facility, for reasons of economy, has been omitted from this project.

J. Electrical System Design

The electrical system design covers the supply cable from/to the NELH power house, internal wiring associated with pond operation and a load bank. The supply cable is run through a buried concrete encased conduit which connects the existing hand hole (B) at NELH with the service entrance at the pond power platform.

Electrical service lines to the two remote pumps are run through buried conduits to the appropriate service poll boxes.

Two load banks are provided. These load banks will be used during the test phase before hook-up with NELH as dummy loads. After the pond is in full service the banks will be used to prevent the pond from boiling whenever the produced electricity has nowhere to go.

K. Power Distribution Plan

The power distribution plan is shown on SPOTEC Drawing No. 20 "Electrical Site Plan." The design of this connection to the NELH system is left for the construction phase because the NELH system arrangement at this time is not now known.

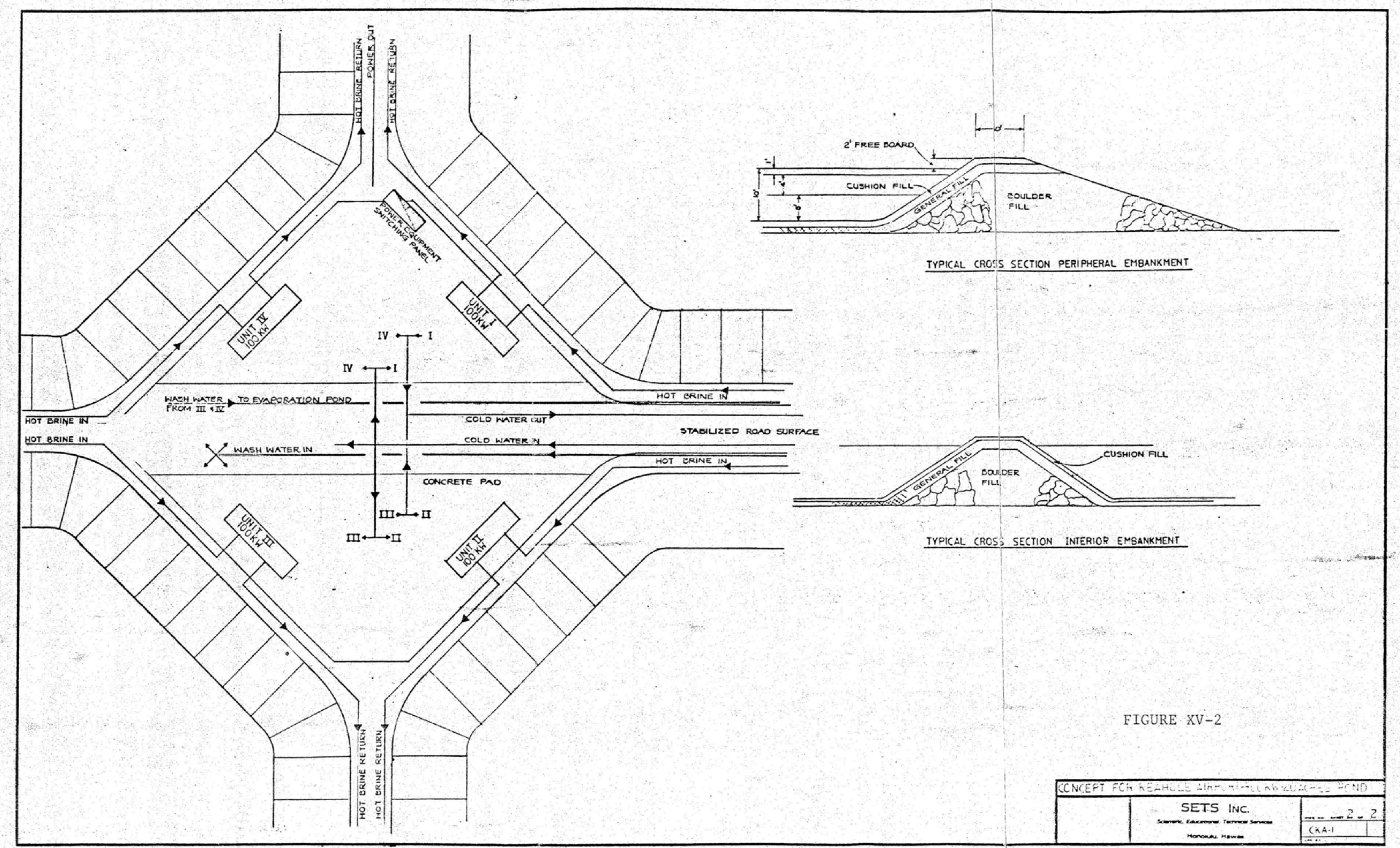

HOT BRINE RETURN
POWER OUT
HOT BRINE RETURN
POWER EQUIPMENT SWITCHING PANEL
UNIT IV 100 KW
UNIT I 100KW
UNIT III 100KW
UNIT II 100 KW
IV I
III II
WASH WATER FROM III & IV
TO EVAPORATION POND
HOT BRINE IN
COLD WATER OUT
STABILIZED ROAD SURFACE
WASH WATER IN
COLD WATER IN
CONCRETE PAD
2' FREE BOARD
CUSHION FILL
GENERAL FILL
BOULDER FILL
TYPICAL CROSS SECTION PERIPHERAL EMBANKMENT
TYPICAL CROSS SECTION INTERIOR EMBANKMENT
SETS Inc.
Scientific, Educational, Technical Services
Honolulu, Hawaii
2 2
CKA-1

FIGURE XV-2

The distribution cable is shown to be underground. This is expensive. An alternate arrangement should be sought during the construction phase to attempt to reduce costs.

L. Security System Design

The entire installation of the two ponds and associated equipment is rather passive. The operators and the general public will have to go to some extra effort to get injured.

The slope of the interior embankment walls is such that a person easily can crawl out of the power pond water and the evaporation pond is too shallow to be dangerous.

The hot brine is a potential hazard. The specific gravity of the brine in the storage zone and in the gradient zone is so high however that humans only with difficulty can become immersed. Exposed valves on the hot brine circuit must be secured with locks or locked covers. The equipment on the power pad must be secured with a fence.

Vandalism is a potential problem. In general the ponds are so big that only a concerted assault would cause serious damage. An occasional beer can or rock will hardly be noticed.

Deliberate sabotage such as puncturing of the power pond liner cannot be stopped by a cyclone fence.

We conclude that a complete fence around the installation is not justified in view of the hazards versus the cost. Selected sensitive operations areas, however, must be protected by individual fencing.

M. Performance Predictions for Pond and Power Plant

The performance of the solar pond will depend primarily upon several factors; namely the seasonal incoming solar radiation, pond geometry and hypsography, the maintenance of the pond for stability and clarity, the rate of heat lost from the boundaries and the rate of heat removal, and the efficiency of the equipment used to convert the thermal energy to electrical energy.

The Ke-ahole pond, sized as one acre on the bottom, exceeds a one acre surface area due to the sloping sides. Insolation observations obtained both from the Ke-ahole site and for the Ke-ahole area provided the range of anticipated incoming energy. In addition, given the observed range over several years of air temperature, surface water temperature (coastal), humidity, cloud cover and wind speed the surface heat exchange in cal/sq cm/day was computed using the heat exchange relationships described in Bathen (1975). The results of these computations were then compared to insolation historical observations taken in partial periods of past recent years. In this way seasonal isolation (surface heat exhange) to the likely extreme condition for the site was established. This range extends from a winter potential low of 214 cal/sq cm/day to a summer potential high of 731 cal/sq cm/day. Over a typical year, however, the site is expected to receive an average of approximately 484 cal/sq cm/day.

Conversion of the seasonally varying insolation to thermal energy involves additional computations as described in the conceptual design, performance section, prior. Considering the pond configuration and a conversion efficiency as 0.64 of carnot efficiency, and estimating the pond boundary losses given the site and probable construction materials, the amount of thermal energy likely available is expected to range from 14.3 x 10 to 48.8 x 10 BTU/hr in the extreme case. These heat inputs, provided to the power conversion equipment manufacturer, resulted in the selection of equipment for electrical power conversion. The use of OTEC cold water for cooling further enhances the possible output.

It is anticipated in the extreme case that the short-term average electrical output could, following pond warmup to stability, range between 12 KWe to 41 KWe without the OTEC enhanced cooling, and 15 KWe to 51 KWe with OTEC cooling if all available heat were to be utilized. Considering in addition, possible power generation equipment sub-specification performance, the extreme, short-term average busbar power available is expected to range between 11 KWe (February minimum) to 31 KWe (July maximum). The annual average available busbar power is expected to be about 23 KWe.

Any performance anticipation for the Ke-ahole pond must keep in mind that the pond output, as ultimately seen at the busbar, will be influenced by key factors such as the actual future insolation rates, the final pond construction configuration and materials, future site environmental factors such as wind and dust-debris, and the anticipated performance of both pond maintenance and power generation equipment.

IX. CONSTRUCTION BUDGET FOR THE 15/30 KWE SPOTEC POWER PLANT

The estimated cost for constructing the 15/30 KWe SPOTEC Power Plant is presented in Table IX-1. Two basic options are costed: (1) A Minimum Facility to produce 15 KWe average gross power and 30 KWe peak power, (0.64 acre collection area, at the top of the storage zone and 0.5 acre at the pond bottom with a 2:1 interior embankment slope), and (2) A larger facility to produce up to 27 KWe average gross power and 30 KWe peak power (1.2 acre collection area at the top of the storage zone and 1.0 acre at the pond bottom with a 2:1 interior embankment slope).

The costs would be spread over 18-24 months and could be spread over a longer period, say to 36 months, without significant extra cost (except inflation). The project expenditure could be adjusted to cover three fiscal years with expenditure in the first two fiscal years being about equal and totaling about 80-90% of the total cost.

There are additional design options available which will affect costs. For example, pond sizes other than those two options chosen here could be chosen.

The cost estimates presented in Table IX-1 are based on adherence to the construction plan given in Chapter X.

Table IX-1.

COST

ENERGY CONVERSION SYSTEM

	27 KW 1.2 Acre Collection Area	15 KW 0.64 Acre Collection Area
Pond Civil Work	$222,326	$164,018
Power Plant	80,000	80,000
Liner	35,000	21,000
Plumbing	60,000	52,000
Pumps	10,600	10,600
Diffusers	3,400	3,000
Building	5,000	5,000
Electrical	57,800	57,800
Instrumentation	35,000	32,000
Wave Suppression	7,000	5,100
Misc. Equipment	20,000	20,000
Labor	40,000	40,000
	$576,126	$490,518

BRINE MAKING FACILITY	2 Acre Evaporation Area	1 Acre Evaporation Area
Pond Civil Work	$ 98,240	$ 46,031
Liner	7,000	3,500
Plumbing	2,500	2,500
Spray Equipment	34,120	17,120
Fuel	16,000	8,000
	$157,860	$ 77,151
OTHER		
Engineering Supervision & Management	$95,000	$ 95,000
Contingency	20,000	20,000
	$848,376	$682,669
OPTIONS		
Power House	$ 22,000	$ 22,000
Office/Visitor/Storage Building	29,300	29,300
TOTAL	$899,676	$733,969

X. CONSTRUCTION PLAN FOR THE 15/30 KWE SPOTEC POWER PLANT AND BRINE PRODUCTION FACILITY

A. Project Management

The SPOTEC project at Ke-ahole Point requires the efforts of a number of disciplines within the construction industry which are unlikely to be found within the capabilities of one contractor. Since the major effort and cost item is the pond construction itself, it is reasonable to assume that earth moving contractors would respond to a bid invitation as general contractor, with the plumbing, electrical and energy conversion equipment disciplines being supplied by subcontractors. This approach is the east complicated for the owner, but the most expensive.

Inspection of the construction plan schedule (Table X-1) reveals that, because of the desirability of producing brine at the site, all the construction, exclusive of the heavy earth moving, can be accomplished by a small crew at a comfortable pace, and be completed by the time sufficient brine for start-up has been produced.

With this in mind, we propose a basic plan for the project management which we believe will be the most economical while providing long term benefits for the project.

The following are the main parts of this plan.

Item 1 Responsibility for the over-all project management is delegated to a firm with expertise in solar pond science and technology, such as SETS, Inc., as an engineering management company which would perform the contract management and provide the engineering supervision during the construction phase.

Item 2 The project manager, through normal bid procedure selects a grading contractor who will perform the earth moving work required for the project and an electrical contractor for the electrical work.

The project manager would further act as the purchasing agent for all the materials required for the project, pond liner, energy conversion equipment, piping, etc.

Item 3 The project manager hires a site engineer and a crew of up to four workers and a foreman who will perform all the field work required to complete the project. This crew could be part of the NELH staff, specifically assigned to SPOTEC, under daily supervision of the project engineer. It would then be expected that one or more members of this crew could be retained by NELH for the operation phase of the pond. If NELH is not to be involved, a small local general contractor might furnish the labor.

Table X-1.

30 KWe SOLAR SALT GRADIENT POND POWER PLANT & ASSOCIATED FACILITIES PROJECT SCHEDULE

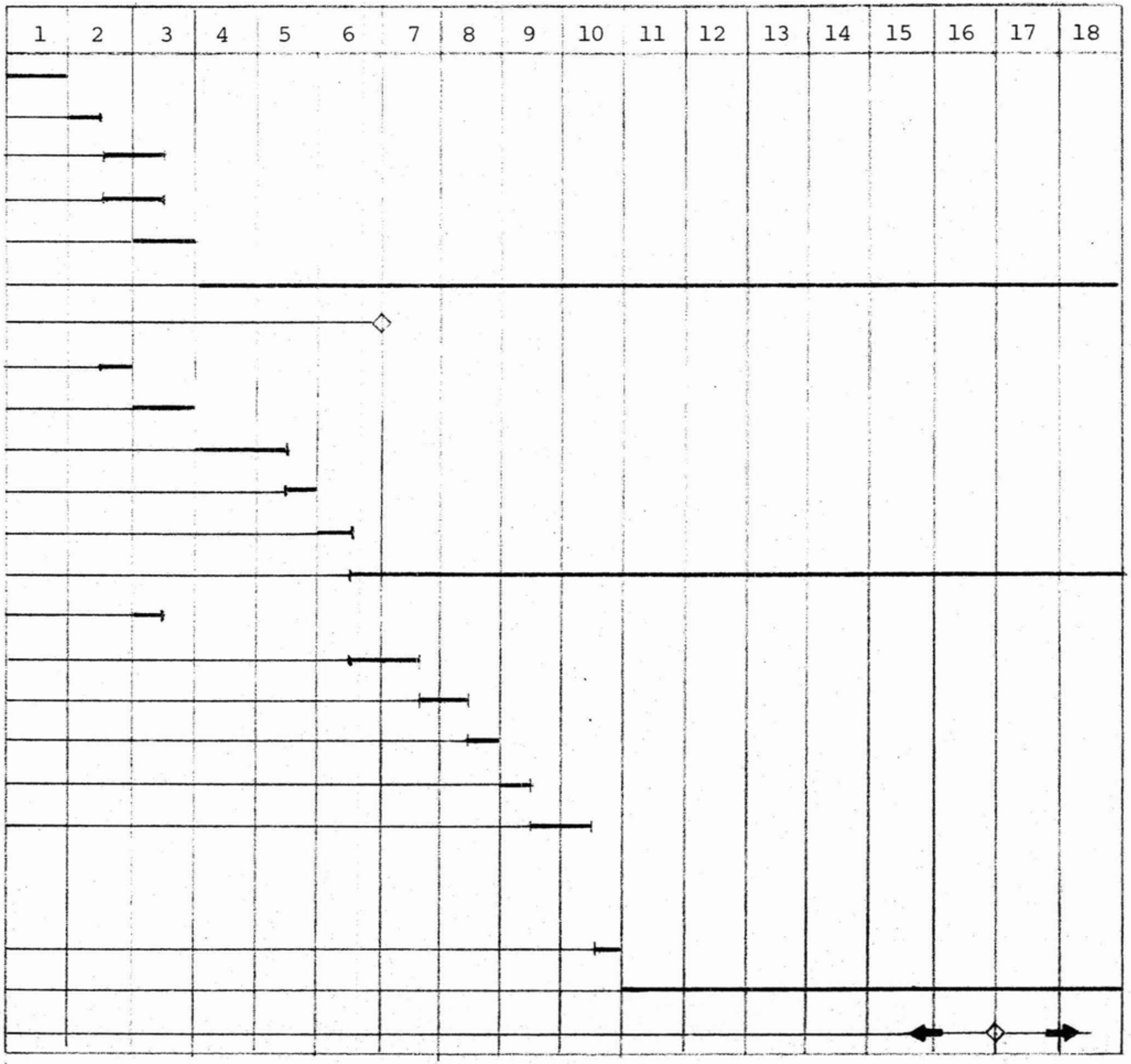
Construction

Notice to Proceed

1. Mobilization
2. Evaporation Pond Platform
3. Electrical
4. Embankments & Liner
5. Water Supply & Spray Equip.
6. Start Spraying
7. Decision on Salt Purchase
8. Power Pond Platform
9. Embankment
10. Instrumentation
11. Liner Installation
12. In Pond Piping
13. Brine Transfer
14. Power House & Parking
15. OTEC & Seawater Piping
16. On Pond Piping
17. Brine Make-up
18. Power Conversion Equip.
19. Complete Piping & Electrical Circuit

Start-up

19. Establish Gradient
20. Warm-up
21. Start-up



B. Description and Schedule of Tasks

The major tasks of the construction phase are listed and described briefly here in the order in which they should be performed. The estimated schedule for accomplishing these tasks is presented in Table X-1.

<u>Brine Production</u>

1.	Mobilization:	This period allows the grading contractor to bring his equipment to the site. The crew members will be identified by the project engineer.
2.	Evaporation Pond Platform:	The grading contractor will construct the basic platform under the supervision of the site engineer. The site engineer, through daily monitoring, determines the most economical cut-off point for the excavation effort.
3.	Electrical:	The grading contractor installs buried conduit and hand holes between NELH power house and the SPOTEC site. The electrical contractor installs cables and the preliminary service entrance.
4.	Embankment & Liner	The grading contractor will complete the evaporation pond embankments including gates. The crew will assist the liner installation crew during the installation of the liner.
5.	Water Supply & Spray Equipment:	The crew will: lay the 2" pipe line from the sea water supply to the seawater transfer pump; lay a temporary 2" line from the transfer pump to the evaporation ponds; assemble the spray equipment; and install the spray pumps.
6.	Start Spraying:	The 24 hrs/dy spraying operation will commence as soon as sufficient water is available in the evaporation ponds.
7.	Decision on Salt Purchase:	After 3 months of spraying, the brine production rate is well enough established to indicate whether salt purchasing will be necessary in order to meet the proposed start-up date.

Energy System

8. Power Pond Platform: The grading contractor will construct the basic platform under the supervision of the site engineer. The site engineer, through daily monitoring, determines the most economical cut-off point for the excavation effort.

9. Embankments: The grading contractor builds the basic embankment including gravel layer and cushion layer ready for liner installation.

10. Instrumentation: The crew installs fixed and buried instrumentation sensors and associated wiring.

11. Liner Installation: The liner manufacturer provides an installation supervisor. The local crew will be increased to a total of 15 men for 2 days. Three bundles of prefabricated liner weighing approximately 5500 lbs. each will be placed by flatbed truck inside the pond and unfolded by the crew.

12. In Pond Piping: The crew installs manifolds and hot brine return pipe.

13. Brine Transfer: The crew installs temporary 2" brine transfer pipe and pump, transfer brine as required.

14. Power House and Parking: The grading contractor prepares parking area and power conversion equipment platform. The grading contractor has now completed his contract. The crew constructs the concrete platform for the pumps and generating equipment and erects the 6-foot fence.

15. OTEC & Seawater Piping: The crew assembles and installs, the permanent OTEC supply and return piping and, the permanent seawater supply and return piping, between the NELH supply point and the power house.

16. On Pond Piping: The crew installs all the on pond piping: hot brine supply & return, wash water supply and return, evaporation pond permanent supply, wash water return pump.

17. Brine Make-up: The crew installs the tanks, pumps and piping required for the brine make-up and gradient maintenance on a concrete pad provided by the grading contractor.

18. Power Conversion Equipment: The power conversion equipment will be installed by the supplier. Electrical work on the power platform by electrical contractor and the crew completes the piping to the generating equipment.

19. Complete Piping and Electrical Routing: The crew makes the final pipe connections to complete the circuits, switches the temporary evaporation pond supply piping into the permanent set-up and installs the wave suppression grid. The electrical circuits for the power and evaporation ponds are completed by the electrical contractor.

XI. START-UP, OPERATION AND MAINTENANCE PLAN FOR THE 15/30 KWe SPOTEC POWER PLANT

The design depth of brine and water in this pond is 10 feet. The 10 feet are divided into 3 zones. The bottom or storage zone contains 22% brine and is 5 feet deep. The intermediate or gradient zone contains carefully constructed layers of brine with a salt content of 22% at the lower layer and 3.5% at the upper layer. This zone is 4 feet thick. The top zone contains seawater and is 1 foot thick.

The design depth of 5 feet for the storage zone is a compromise number arrived at by an evaluation of economic constraints and the power consumption profile. This pond will function, though at a reduced level, with as little as 3 feet of brine in the storage zone.

The predicted output of the brine making facility indicates that 5 feet of brine, (3 feet for the storage zone and 2 feet as make-up for the gradient zone), will be available by the middle of Month #10.

Since it is desireable to begin to produce some power at as early a date as possible, this start up plan is based on an initial storage zone depth of 3 feet.

A. Start-up

1) Gradient Zone Establishment

The successful operation of the solar salt gradient pond is to a large measure dependent on the careful maintenance of the gradient zone. The gradient maintenance equipment as designed for the 5 feet storage layer is easily modified for temporary use with a 3 feet depth.

Step 1 Fill pond with 5 feet of 22% brine.

Step 2 Connect gradient maintenance supply hose to OTEC water pump by-pass line.

Step 3 Place gradient maintenance devices at the center of the pond in 5 feet of brine.

Step 4 Position diffuser at a level 3 feet above pond bottom.

Step 5 Start pumping OTEC water (after treatment) into the pond early in the morning. Pump at the rate of 250 GPM continuously for 3 hours. This will raise the pond surface by ~1.33-in.

Step 6 Cease pumping for ~2 hours. Measure salinity profile at several places in the pond. Particularly check to see if salinity above the diffuser level is uniform.

Step 7 In the afternoon, move the diffuser up by 2.66-in. Resume pumping, at 250 GPM for 3 continuous hours. This will raise the pond surface by another 1.33-in. approximately.

Step 8 The next morning, measure salinity profile, then move up the diffuser by 2.66-in. Repeat steps 4-6.

Step 9 Repeat step 7 each day until the diffuser reaches the pond surface (i.e., after it has been moved up at 2.66-in. Increments for a total of 18 times) this completes the gradient establishment process.

Step 10 With the diffuser located at 7 feet above the pond floor, pump 1-ft. of treated OTEC water to fill the surface zone. Approximately 26 hours of continous pumping at 250 GPM is required to complete this zone.

The gradient is now established and the brine will begin to warm up. The remaining 2 feet of brine will be inserted in 1 inch increments as it becomes available through the brine make-up equipment.

The density gradient resulting from this successive step mixing is depicted in Figure XI-1. Table XI-1 gives the density and concentration at each mixing step.

2) Warm-Up

The length of time required for the brine temperature to rise from ambient to 200 degrees F is dependant on several variables and therefore is very difficult to predict. Time of year, actual insolation during this time, actual thermal conductivity of the pond bottom and embankment, clarity of the water all influences this process. Encouraged by reports from Arizona and small local ponds we believe the operating temperature can be reached six months after establishment of the gradient zone. The warm-up will proceed more rapidly at first but as the brine temperature reaches 120-150 degrees F the heating will proceed more slowly.

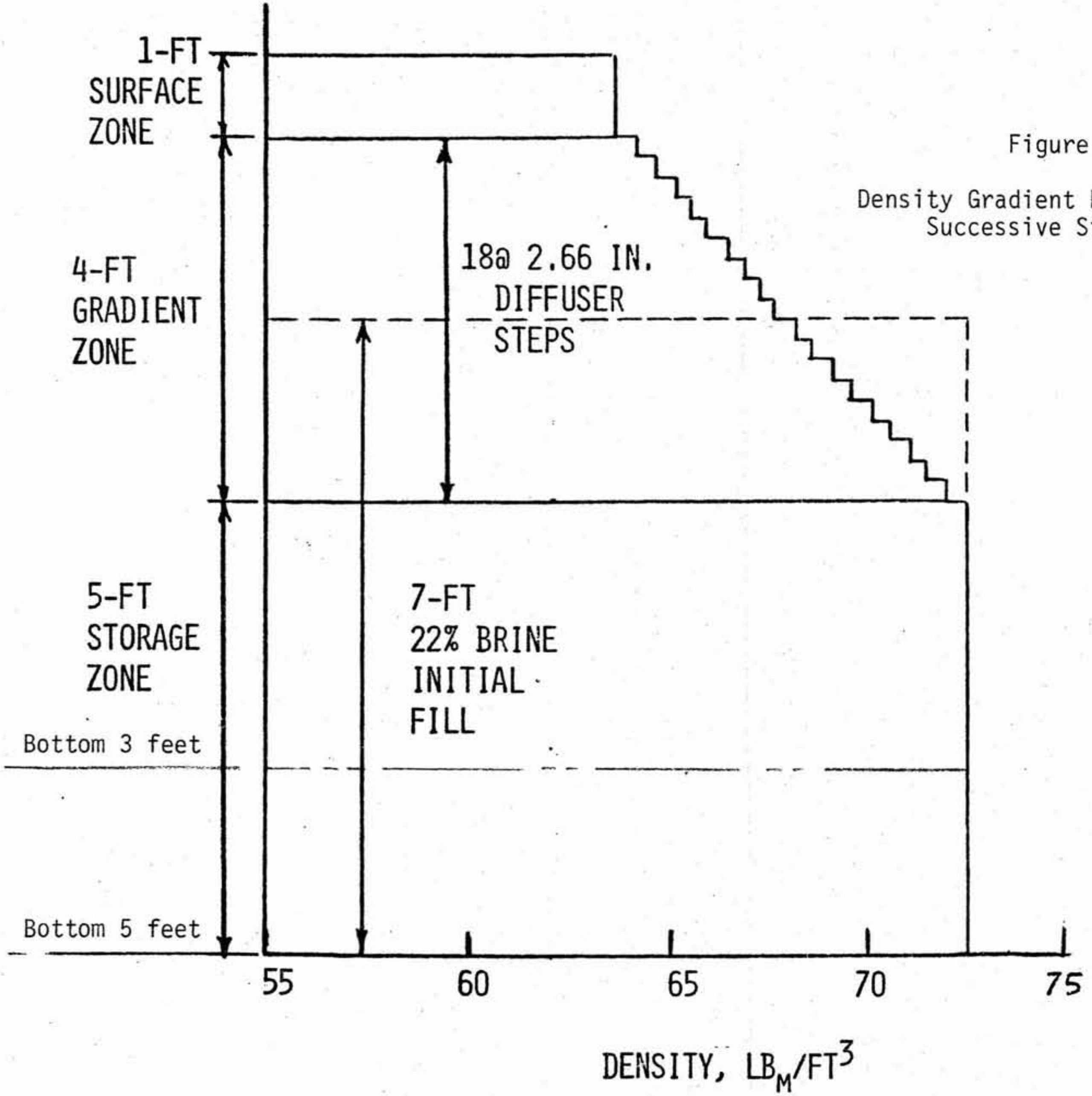
During this warm-up phase, the pond must be maintained with chemical and surface flushing. The instrumentation must be active and records should be kept of the monitored parameters, temperature fluctuations, gradient stability, turbidity, etc.

3) Start-Up

When the brine has reached a temperature of 160-180 degrees F limited test runs may begin. All parameters must be monitored in order to determine how

Figure XI-1.

Density Gradient Resulting from Successive Step Mixing



DENSITY GRADIENT RESULTING FROM SUCCESSIVE STEP-MIXING

Table XI-1.

GRADIENT ESTABLISHMENT: DENSITY AND CONCENTRATION AT EACH MIXING STEP

NO. OF MIXING	VOLUME, FT			DENSITY, lBM/FT^3			CONCENTRATION, WEIGHT FRACTION		
	D_1	D_2	D_3	P_1	P_2	P_3	C_1	C_2	C_3
1	0.11	2	2.11	63.6	72.5	72.0	0.035	0.22	0.21
2	0.11	1.89	2.00	63.6	72.0	71.5	0.035	0.21	0.20
3	0.11	1.78	1.89	63.6	71.5	71.1	0.035	0.20	0.19
4	0.11	1.67	1.78	63.6	71.1	70.6	0.035	0.19	0.18
5	0.11	1.56	1.67	63.6	70.6	70.1	0.035	0.18	0.17
6	0.11	1.45	1.56	63.6	70.1	69.6	0.035	0.17	0.16
7	0.11	1.34	1.45	63.6	69.6	69.1	0.035	0.16	0.15
8	0.11	1.23	1.34	63.6	69.1	68.6	0.035	0.15	0.14
9	0.11	1.12	1.23	63.6	68.6	68.2	0.035	0.14	0.13
10	0.11	1.01	1.12	63.6	68.2	67.7	0.035	0.13	0.12
11	0.11	0.9	1.01	63.6	67.7	67.3	0.035	0.12	0.11
12	0.11	0.79	0.9	63.6	67.3	66.9	0.035	0.11	0.10
13	0.11	0.68	0.79	63.6	66.9	66.4	0.035	0.10	0.09
14	0.11	0.57	0.68	63.6	66.4	65.9	0.035	0.09	0.08
15	0.11	0.46	0.57	63.6	65.9	65.5	0.035	0.08	0.07
16	0.11	0.35	0.46	63.6	65.5	65.1	0.035	0.07	0.06
17	0.11	0.24	0.35	63.6	65.1	64.6	0.035	0.06	0.05
18	0.11	0.13	0.24	63.6	64.6	64.1	0.035	0.05	0.04
19	0.11	0.02	0.13	63.6	64.1	63.7	0.035	0.04	0.036

SEA WATER SALINITY = 3.5%; STORAGE SALINITY = 22%; T_A = 75°F

$$D_3 = D_2 + D_1$$

$$P_3 = (D_1P_1 + D_2P_2)/D_3$$

$$C_3 = (D_1P_1C_1 + D_2P_2C_2)/(D_1P_1 + D_2P_2)$$

much heat can be removed from the brine without causing damage to the storage zone

B. Operation

1) Plan

This plan outlines the necessary steps required for the continuous operation of the completed SPOTEC pond. It is based on the belief that the basic information used for the development of the original specifications is correct. The start-up phase and the initial experimental runs may well show areas where adjustments of the specifications are needed. The impact on the over-all operation should, however, be negligible.

The power pond and associated machinery is designed for manual operation. However the equipment specified, in areas where future remote control is likely, is designed to accept remote control equipment.

There is very little information available in the literature based on actual experience with the daily operation of solar salt gradient pond power plants. This being the case, it is desireable to develop such information from the experience with this pond, so although the time scale of changes in the pond conditions is large, in the order of weeks, we propose that the facility be monitored on a daily basis by a full time employee. The mechanics of mixing brine, switching flows, adding biocide is not very time consuming but careful monitoring and recording of the instrumentation is. This individual would also be required to do routine maintenance of the equipment, with outside help for bigger jobs such as heat exchanger cleaning.

Full time production of maximum sustainable seasonally adjusted electrical power is dependant on the amount of hot brine that may be pumped through the boilers without lowering the average temperature of the storage zone. The predicted extreme amounts for this pond are for the summer 230 GPM and for the winter 86 GPM. The corresponding numbers for the OTEC water are 182 GPM and 68 GPM.

The wash water requirements change seasonally from a summer extreme high of 21 GPM to a winter extreme low of 8 GPM. The wash water return extreme changes from 12 GPM to 5 GPM.

The salt migration in the pond stays constant and requires a daily reinsertion of 425 gallons of 22% brine. The gradient maintenance requirements will vary seasonally, the specifics to be verified in testing. Repair of the gradient zone will be accomplished as required.

For maximum operation the biocide chemical requirement could be met using either copper sulphate (1 lb/100 m at pH 5-6) or Chlorine (1.5 ppm). Chlorine appears to work successfully in local conditions. It is predicted that 0.1 gal/day is suffice, however, this number is subject to revision after operational experience has been acquired. Daily biocide replenishment is introduced through the wash water gradient maintenance and hot brine return diffusers, or via occasional shock concentrations added as required seasonally to control bio-growth.

2) Operational Tasks

Hot Brine Circuit: The brine flow rate is controlled by the throttling action of butterfly valves in the two parallel brine circuits in the power house. Flow indicators are provided for each unit. The filters require periodic back flushing with brine or sea water. Replacements for the diffused salt and biocide is inserted in the loop just ahead of the hot brine return diffuser.

Cold OTEC Circuit: The OTEC water flow rate is controlled by the throttling action of butterfly valves in the two parallel OTEC circuits in the power house. Flow indicators are provided for each unit, the filters require periodic back flushing with sea water.

Surface Wash Water Supply: The surface wash is accomplished daily at a constant flow rate of 56 GPM. The adjustment for extreme seasonal changes are done by varying the length of time of pumping from 9 hours per day in the summer time to 3 1/2 hours in the winter time. The supply line filter require periodic back flushing. The biocide mixture is drained from the make-up tank into the diffuser line one hour before the end of the pumping cycle.

Surface Wash Water Return: The surface wash water with its increased salinity is normally routed from the pond to the evaporation facility but may also be returned to the NELH water return. In the first case the residual biocide will be deposited in the evaporation pond in the second case the water will be mixed with other laboratory water ensuring that the concentration will meet the environmental requirements. A pump and valves are located on the embankment near the surface wash collector.

Brine Make-up: Salt is continually diffusing upward from the storage zone at a rate of .014 lbs/sq.ft./day which at the interface between the gradient zone and the surface zone equals 778 lbs./day. To replace this salt, 425 gallons of 22% brine must be injected into the storage zone.

Stored brine, seawater or bulk salt is mixed in the 600 gallon make-up tank to produce 22% brine. This brine is then pumped into the hot brine return line at a rate of 10 GPM. The make-up tank is located on a concrete pad near the hot brine return loop. It receives sea water from the evaporation pond supply line, and brine directly from the evaporation facility. The biocide mixture is drained into the tank from the biocide make-up tank when required. Pet cocks for sampling are provided. The filters in the supply lines require periodic back flushing. The make-up brine is delivered to the hot brine circuit by means of a pump and valves located in front of the tank.

The frequency with which these tasks will probably need to be carried out is given in Table XI-2.

C. Preventative Maintenance Plan

The equipment specified for the SPOTEC power plant is all compatible with hot and cold brine service. The tolerances on the actual behavior of each piece of equipment, under the circumstances found at Ke-ahole, are too great to predict the proper time intervals for services. This section therefore will only indicate required maintenance, not frequency.

Table XI-2.

15/30 KWe SPOTEC Power Plant

Predicted Operational Task Frequency
1st Year of Operation

	Daily	Weekly	Mnthly	Quatly	6-Mo	Yrly	Remarks
Adjust Hot Brine Flow Rate			X				
Adjust OTEC Flow Rate			X				
Flush Filters			X				
Heat Exchanger Maint.					X		
Adjust Surface Wash Flow Rate			X				
Surface Wash Biocide		X					
Flush Filter			X				
Gradient Maintenance							As required
Brine Make-up	X						
Brine Make-up Biocide		X					
Flush Filter			X				
Weather Monitoring	X						
Pond Monitoring	X						

1) Pond embankment

Periodic visual inspection of embankment for signs of external and internal sagging and erosion.

2) Liner

Periodic visual inspection of the liner for signs of stress and stretching, cuts, secure anchoring and deterioration from weathering. The liner as specified carries a 20-year warranty against failure from aging.

3) Piping

Periodic visual inspection of the piping runs for leaks, cracks, abnormal discoloration, dislocation, signs of strains and condition of supports. The piping materials specified have excellent aging qualities and should provide a lifetime comparable to the liner.

4) Pumps

The pumps and associated electric motors require periodic maintenance according to the manufacturers recommendations. All the pumps have provisions for flushing of shaft seals with seawater. Bearings, seals, brushes and impellers to be replaced on a schedule based on experienced gained through actual operation.

5) Valves

Periodic inspection of valves for leaks, precipitated salts, wear and general operation. Scheduled replacement with overhauled spare valves is envisioned.

6) Filters

Periodic visual inspection for pressure drop, leaks, general condition. Back flushing as required.

7) Energy conversion equipment

The screw expanders reportedly operate with minimal service for a period of 5 years between factory overhauls. The freon system requires occassional refilling. The liquid freon pump must be serviced according to the manufacturer's recommendations.

The stainless steel heat exchangers require periodic servicing for removal of biofouling, salt deposits, corrosion and other matter reducing their efficiency. Flushing with nitrogen gas may be required after each overhaul. The generator and associated control equipment will require periodic maintenance according to the manufacturer's recommendation.

8) Brine

The maintenance of the clarity of the water in the pond, and the control of the non-convective zone is part of the daily operation of the pond.

9) Instrumentation Systems

The monitoring instrumentation systems contain delicate sensors and relatively complicated circuitry. The sensors require periodic calibration and the circuitry should bechecked for shorts and other malfunctions.

D. Damage Control

The equipment assembled to form the SPOTEC power plant is in general quite simple and not particularly prone to catastrophic failure beyond a temporary shut down. The only real concern is failure of the pond liner and loss of brine and stored energy. The experience with leakage in existing ponds has largely been confined to minor punctures and local failure of a seam. In a few cases the liner has ruptured because of a shift in the substrates. The design of this pond reflects these concerns. The requirement for using heavy equipment in the earth-moving phase and the relatively thick layers of general fill and cushion fill is a result of this concern.

At Ke-ahole the major concern is that a substantial leak would cause the loss of the brine, which is a major part of the capital investment. Contamination of the subsoil and surrounding land is not serious as the brine quickly will find its way to the ocean and dilution.

Catastrophic massive failure of the embankment may be caused by earthquakes, tsunamis or storm driven waves. In these cases damage control appears impossible. The pond is located well inland of the reach of previous storm driven waves. The damage of tsunami and earthquake effects are beyond calculation.

In the case of a slow leakage the damage may, with difficulty, be repaired from the surface of the pond, if the leak can be located. Leak location detector equipment has been included in this design.

If a substantial leak occurs, steps should be taken to immediately transfer the storage zone brine to the 2-acre evaporation pond. This pond has sufficient capacity to hold the 5-acre feet of brine required for a restart. The brine contained in the gradient zone would probably be lost, unless underwater repairs could be accomplished at water temperatures less than 100% F. In any event a minimum of 6 months of down time would be the result of transfer of the brine to a storage pond because of the loss of heat.

The pond and the general site would be exposed to petty vandalism and general littering by curious bypassers. This annoyance could be mostly eliminated by a cyclone fence around at least the ponds and this is part of the design.

XII. BRINE SUPPLY

A. Brine Requirements

In this section the brine supply requirements for the energy pond and the means by which they can be met are addressed. There are two requirements or stages of implementation of the energy pond which can be considered: (1) the minimum pond configuration required to begin some level of operation and energy extraction and (2) the designed configuration for full operation.

A minimal requirement for the start-up configuration is that enough brine be available to form a storage layer of 3-feet thickness and a transition layer of 4-feet thickness. In order for the transition layer to be sufficiently stable against convection, a storage layer density of 1.18 is required. The transition layer would grade linearly in density from 1.18 at the bottom to near 1.0 (sea water) at the top. The 1.18 density brine will have a salt concentration of 22% by weight (see Figure XII-1). Thus, the minimum start-up requirement for th baseline pond is for about 5 acre-feet (2.18×10^5 ft or 1.64×10^6 gal) of 22% brine. This is equivalent to about 1500 tons of dry NaCl salt.

The energy pond designed configuration for full operation is 5 feet of storage zone and 4 feet of transition zone. This means for the baseline pond about 8 acre-feet (3.49×10^5 ft^3 or 2.62×10^6 gal) of 22% brine, remembering that the pond size at the final level of the top of the transition zone is about 1.2 acres because of the outward-sloping pond walls. The equivalent amount of dry salt is about 2400 tons.

There is no requirement for new salt during pond operation if the surface wash water containing the salt that diffuses upward though the transition zone is retained and reconcentrated by evaporation. The amount of 22% brine needed to replace the salt which diffuses upward is about 420 gal/day.

For the minimum design pond the brine requirements are about half those for the baseline design pond.

B. Methods for Meeting Requirements

1) Manufacture Brine Locally

a) Passive evaporation of seawater

An age-old method of manufacturing salt, still used today, is by passive solar evaporation of seawater. The Ke-ahole site is attractive for solar ponds partly because of the availability of seawater for salt supply. In the solar pond case, only 22% NaCl brine is needed, not dry salt. Refering to Figure XII-1, this requires evaporation of 6.8 units of seawater to achieve one unit of such NaCl brine. The data in Figure XII-1 encompasses the effects of precipitation of salts other than NaCl and also any nonlinearities due to lack of volume conservation in the evaporation process. For the minimum start-up configuration, about 5 acre-feet (1.5 acre-meters) of 22% brine is required. In turn, this would require evaporation of 6.8 x 5 = 34 acre-feet (10.2 acre-m) of

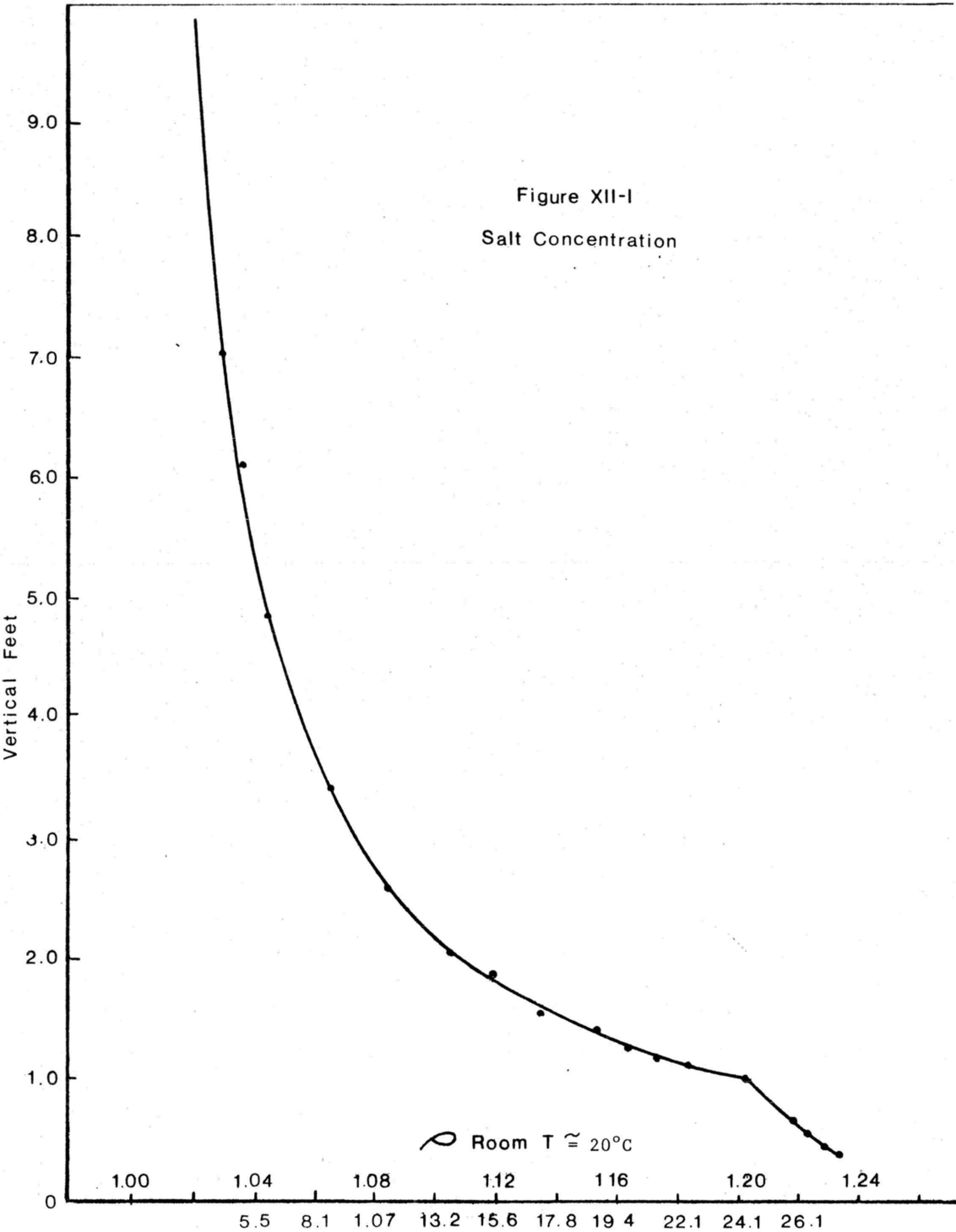


Figure XII-I
Salt Concentration
Vertical Feet
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
Room T ≅ 20°C
1.00
1.04
1.08
1.12
1.16
1.20
1.24
5.5
8.1
1.07
13.2
15.6
17.8
19 4
22.1
24.1
26.1
WT % Dissolved Solids

sea water. However, the base-line evaporation pond has an area (2 acres) twice that of the energy pond (1 acre), so 17 feet (5.1 m) of evaporation in the evaporation pond is required. Similarly, for full operation 27.2 ft. (8.2 m) of evaporation is required in the two-acre evaporation pond.

Model net evaporation rates in the general vicinity of the Ke-ahole airport are ~5.5 ft/yr (1.8m/yr). Actual NELH site measurements yield a slightly higher value of 7.6 ft/yr (2.3m/yr). However, these are evaporation rates for fresh water. Even seawater (with 3.5% salinity) evaporates 5% more slowly. By the time a 20% brine is achieved, rates have slowed to 80% of the fresh water rate and the time-integrated slowing in production of a 22% brine is about 12%. The net 7.6 ft/yr (2.3m/yr) value corresponds to the difference between gross evaporation of 9.6 ft/yr (2.9m/yr) and rainfall of 2 ft/yr (0.6m/yr). Therefore, corrected for salinity slowing, the expected pan evaporation rate is 9.6 ft/yr x 0.8 - 2 = 5.7 ft/yr (1.7m/yr).

Thus, based on our requirements for minimum operation of 17 ft (5.1m) of evaporation in the evaporation pond, it would take a "lead time" (time between inital operation of evaporation pond and filling of energy pond) of 17 ft/5.7 ft/yr = 3.4 years. In fact, the base-line construction plan calls for a lead time of 0.5 years. Thus, without utilizing any evaporation enhancement techniques, one would be able to produce 15% of the required salt, and the rest would have to be purchased. Similarly, the time required to produce the brine needed for full operation would be 5.4 years. These production times could be shortened in proportion to an increase in evaporation pond size. For example using a 10-acre evaporation pond would result in production times for minimum operation of 0.34 years or 4 months and for full operation of 0.54 years or 6.5 months. In fact, the site plan, which is part of this design, contains provisions for an evaporation pond of up to 10 acres in area, although a 2-acre facility is the base-line design.

The trade-off of pond area versus production time will involve cost as well as other factors. The possibility of active enhancement of evaporation must be considered before choosing a baseline approach, however.

b) Active Enhancement of Evaporation

There are techniques which can be used to enhance passive evaporation. For example, experience has shown that making the bottom of the shallow evaporation pond black and raising the temperature of the brine can increase salt production by ~20%. However, this is an added cost and the effectiveness of an initially black bottom diminishes as white salts other than NaCl (notably CaSO4) precipitate during brine production. Thus, it might be possible in this way to increase the production rate by 5% or so for the long term.

An alternative, more attractive approach is to spray brine to increase exposure to the air and to enhance evaporation. This was investigated at length in this design project. Although the site is not ideal for spraying because of high humidity during the day (due to sea breezes), the expected enhancement of evaporation is so great that it raises the possibility that, under favorable circumstances, most or all of the required brine could be manufactured in a 6-month period at the site using the two-acre evaporation pond.

A feasibility calculation from scientific first principles shows that minimum brine for pond start-up could be made in 171 days, assuming spraying for

24 hours a day. This calculation goes as follows.

If air passes through fog, then it looses heat, Q_a , by evaporating the water in the fog.

Q_a = (mass of air)(specific heat of air)(difference between dry bulb and wet bulb temperature plus two degrees F).

The two degree factor is emperical and takes into account the difficulty of achieving saturation of the air emerging from the fog (4).

$$Q_a = M_a\ C_p\ \ (T_{db} - T_{wb} + 2).$$

In this case,

$$T_{db} = 72.5\ ^\circ F$$

$$T_{wb} = 67.1\ ^\circ F$$

C_p = Specific heat of air
= 0.24 BTU/°F/lb.

Hence,

$$Q_a = M_a(0.24)(72.5 - 67.1 + 2)$$

$$Q_a = 0.82\ M_a\ \text{BTU/lb.}$$

If the spray curtain is essentually a plane aligned on the long side of the two-acre evaporation pond (400 feet in length) and is 20 feet high, then,

M_a = (mass of air)(cross section of curtain)
(velocity of air through curtain)

$$M_a = (0.07\ \text{lb/ft}^3)(20\ \text{ft} \times 400\text{ft})(5.3 \times 10^4\ \text{ft/hr}).*$$

* assumes average wind vector amplitude projected $\perp$ to spray curtain of 10 mph

Thus,

$$M_a = 2.97 \times 10^7\ \ \text{lb/hr.}$$

Therefore,

$$Q_a = 0.82M_a = (0.82)(2.97 \times 10^7)$$

$$Q_a = 2.44 \times 10^7\ \ \text{BTU/hr.}$$

But, needed for start up of the energy pond are about 5-acre-feet of brine. This means evaporating

$$6.8 \times 5\ \text{ft} \times 4.37 \times 10^4\ \text{ft}^2 \times 62.5\ \text{lb/ft}^3$$

$= 9.3 \times 10^7$ lbs of seawater.

The required heat (H) to evaporate this much seawater is therefore,

$$H = (9.3 \times 10^7 \text{ lbs})(1000 \text{ BTU/lb})(1.08)$$

$$H = 1.0 \times 10^{11} \text{ BTU},$$

where the last term is the average brine vapor pressure and compensates for the fact that the energy required to evaporate brine increases with salinity.

Since the heat lost in the spray curtain is

$$Q_a = 2.44 \times 10^7 \text{ BTU/hr},$$

then, the time t_m required to produce the minimum required brine for start-up of the energy pond is

$$t_m = H/Q_a = 1.0 \times 10^{11} \text{ BTU/ } 2.44 \times 10^7 \text{ BTU/hr}$$

$$t_m = 4098 \text{ hr} = 171 \text{ days}.$$

This means 171 days of full time (24 hours/day) spraying to produce all brine required for the minimum configuration of the energy pond.

Remember that this calculation is based on the simple (and conservative) configuration of a thin spray curtain, i.e., basically a two dimensional model. An uncertainty is how effective the energy from the air can be transferred to the water in the spray plane. In practice, a three-dimensional spray plume would be used anyway and the energy transfer would occur more easily.

Augmentation of the brine production is possible, for example, by preheating sprayed water (perhaps using solar heating), by enlarging the sprayed area and by introducing a third dimension into the spray curtain.

It is necessary to estimate the rate at which the brine must be recycled through the spray phase. Consider the single cycle water loss rate emperically observed for a single evaporative spray cycle, assuming a spray geometry and wind velocity such as envisioned here. For this, it is appropriate to use the model of Manning et al. (4) corrected for the difference in dry bulb and wet bulb temperatures at the site versus that used in their model. The result is that one should experience 3.0% loss per cycle at Ke-ahole. The previous calculation assumed that the spray geometry envisioned would be sufficient to saturate the air at a temperature 2 degrees F below its actual temperature as it emerged, as indicated by the calculation of Manning et al. It was also calculated that this spray procedure involved evaporation of 1.49×10^6 ft^3 of water in 171 days, or 8.7×10^3 ft/day. With three percent loss efficiency, this means that 2.9×10^5 ft^3/day must be pumped, which is 2.18×10^6 gal/day or 907 gal/min. This estimate is consistent with the estimates of Manning et al. (4) when corrected from differences in pond size, and it is an independent check of calculations made above from scientific first principles.

The cost of equipment and energy for spray enhancement of this magnitude is such as to make it an extremely practical alternative for the Ke-ahole case. Assuming a 24 hour continuous spray operation, one could therefore expect to produce all of the required salt for the start-up configuration in six months.

As will be seen in chapter XIII, the design of the brine production facility is sufficiently oversized in pumping rate and flexible in spray configuration that it should be possible to compensate for at least a factor of two errors in the production rate calculations and still meet the construction plan proposed. Even if not, the construction schedule could be slipped by 6-12 months without serious extra cost. Thus, there seems to be sufficient flexibility in the design and plan to compensate for about a factor of four to eight error in production calculations and estimates.

2) Purchase of Salt

Various options for salt purchase have been considered. In all scenarios the costs associated with transportation total a greater amount than the cost of the salt.

Domestic west coast suppliers include Leslie Salt Co. of San Francisco and Western Salt and Ocean Salt of San Diego. For Leslie, the cost of salt suitable for our application would be approximately $38 ton (including shipping containers but not sacks). The sacks would cost ~$3/ton. Transportation to the Oakland Dock would cost $7/ton plus warfage. Ocean transport would cost $60/ton (estimate from Northland Services Inc.). Overland transport would also be required for the dock in Hawaii to the site, at ~$10 ton , plus warfage at the dock. Allowing for uncertainties in the cost of sack disposal/return and dumping costs, the cost of salt from this source, delivered to the energy pond, is estimated at $130/ton.

This means $130/ton x 1500 tons = $195,000 for the minimum salt required for startup of the energy pond and $312,000 for full operation.

A comparable alternative is Western Salt of San Diego. In this case the salt cost estimate quoted was $52 ton. However this included sacks and transport to the west coast dock. Thus the cost per ton is only $4 greater than for Leslie, while the transportation from San Diego would be about the same as from Oakland. Ocean Salt Co. of San Diego provided an almost identical quote to that of Western Salt. We conclude that $130 ton is a close estimte to the cost of salt purchased from domesic West Coast sources. Foreign sources have also been investigated. A New Zealand source (Domino Salt) quoted a price of $65 ton, 20% higher than the west coast sources, suggesting a total cost comparable or grater than those sources. Taiwan Salt Company quoted about $50/ton at the dock.

Two other types of sources were investigated. One is direct purchase from a Mexican source, Expordata del Sol, in Baha. The other involves purchase from inland U.S. sources (in Utah and Ohio) which sell lower grade salt--but still sufficient for our purposes--for $10-$15 ton. However, the extra transportation cost makes the inland salt more expensive than the West Coast salt.

The Mexican source may be more promising in that cheaper salt may be available with no associated increment to the transportation cost. It appears that barge-and-tug transportation is available on a target-of-opportunity basis, yielding perhaps a significantly lower cost ($50-$100/ton) but probably only in 4000-ton lots.

The conclusion is that it cannot be assumed that salt can be delivered at less than $130 ton, including tranportation and all packing and storage costs. However, there may be some transportation arrangements such as associated with the Mexican source which could reduce the cost consideribly.

C. Recommendations

It seems clear that the most desirible source of salt for the solar energy pond is to produce brine locally by spraying. This method was selected as the baseline design.

The advantages of making brine verses purchasing salt are more than just the obvious, very large, cost savings. With brine as the available product at the site instead of salt crystals, there is much less handling required. It is after all brine and not salt that is needed and used. All the brine needed for the minimum energy pond can be held in the salt production ponds and pumped into the energy pond as needed. Also eliminated is the problem of dissolving the salt crystals in the energy pond, a process not found rapid at other facilities.

The salt production facility would satisfy other needs in addition to producing the initial brine. It will be necessary to reconcentrate brine to restock the energy pond because of diffusion of salt upward through the gradient zone, so that an evaporation pond is needed anyway (although this production facility is larger than required). Further, if there were to be a failure of the energy pond liner or if for some other reason the energy pond was in danger of loosing its brine, the salt production facility, as designed here, can act as a rapidly accessable storage pond for the brine in the energy, pond thereby saving a considerable expense and time in bring the energy pond back into operation after repair.

It must be remembered, though, that the calculations made to predict the brine production rate are only approximate. The actual conditions experienced at the site during production can vary from those assumed.
Also, the effeciency of transfer of heat from the air to the sprayed water to cause evaporation is uncertain in any spraying configuration and wind conditions until actually tried. It seems clear, however, that there is sufficient available adjustment in spray configuration and pumping rates and schedules to compensate for any resonable error in design. Also, the conservatively calculated production rates indicate such rapid production that even a factor of four to eight worse production rate would not seriously compromise the project. And, in the end, salt could be purchased if absolutely required.

XIII. ENGINEERING DESIGN OF BRINE PRODUCTION FACILITY

The baseline design of the brine production facility is determined by the brine requirements for the baseline solar pond design. This design is carried through this section. The alternate or minimum design solar pond requires about half the brine as for the baseline design. Thus the reader can easily convert the design given here to the minimum design required, i.e., half size.

1. Base Line Design

Table XIII-1.
Base Line Design

Four Cells Side by Side	Total Area	2.3 acres
Rectangular Cell	Bottom Area	20045 sq.ft.
Embankment Height		2.5 ft.
Embankment Slope, Both Sides		1 1/2:1
Path Width		4.5 ft.
Material Required for Embankment and Cushion Fill		6012 cu.yd.
Liner Required		90230 sq.ft.
Brine Depth Nominal		18 in.
Water Surface Area		2 acres

2. Minimum Design

Table XIII-2.
Minimum Design

2 Cells Side by Side	Total Area	1.2 acres
Rectangular Cell Bottom Area		20045 sq.ft.
Embankment Height		2.5 ft.
Embankment Slope, Both Sides		1.5:1
Path Width		4.5 ft.
Material Required for Embankment and Cushion Fill		3090 cu.ft.
Liner Required		45115 sq.ft.
Brine Depth Nominal		18 in.
Water Surface Area		1 acre

B. System Components and Site Layout

The basic components of the baseline system are the four half-acre evaporation ponds, a seawater supply, an energy pond waste surface wash water supply, a spray system, a brine delivery system to the energy pond brine make-up tank, and an instrument system.

The basic layout of the facility on the site is shown on drawing number SPOTEC 24 (Figure XIII-1). The instrument system is discussed along with the energy pond instrument system in section VIII-H.

C. Evaporation Pond

The base-line design of the evaporation pond assumes a two-acre, four-cell evaporation pond with dike height of 2 1/2 ft. The pond would be lined with a 35 mil plastic material to prevent seepage. The pond dikes are to be shaped crushed basalt all of the same size from the same source as for the energy pond.

D. Spray System

The following is a brief description of the proposed system.

The passive evaporation pond is divided into four cells. The cell into which the water is pumped has the lowest salinity. The water level in the adjacent cells is held at decreasing levels so gravity flow will move the brine through the cells with increasing salinity. Until it gets pumped out of Cell #4. The spraying system is also separated into 4 units, each unit spraying on its own cell.

The total amount of brine being sprayed is 1600 GPM for the 2-acre pond thus each subunit will spray 400 GPM.

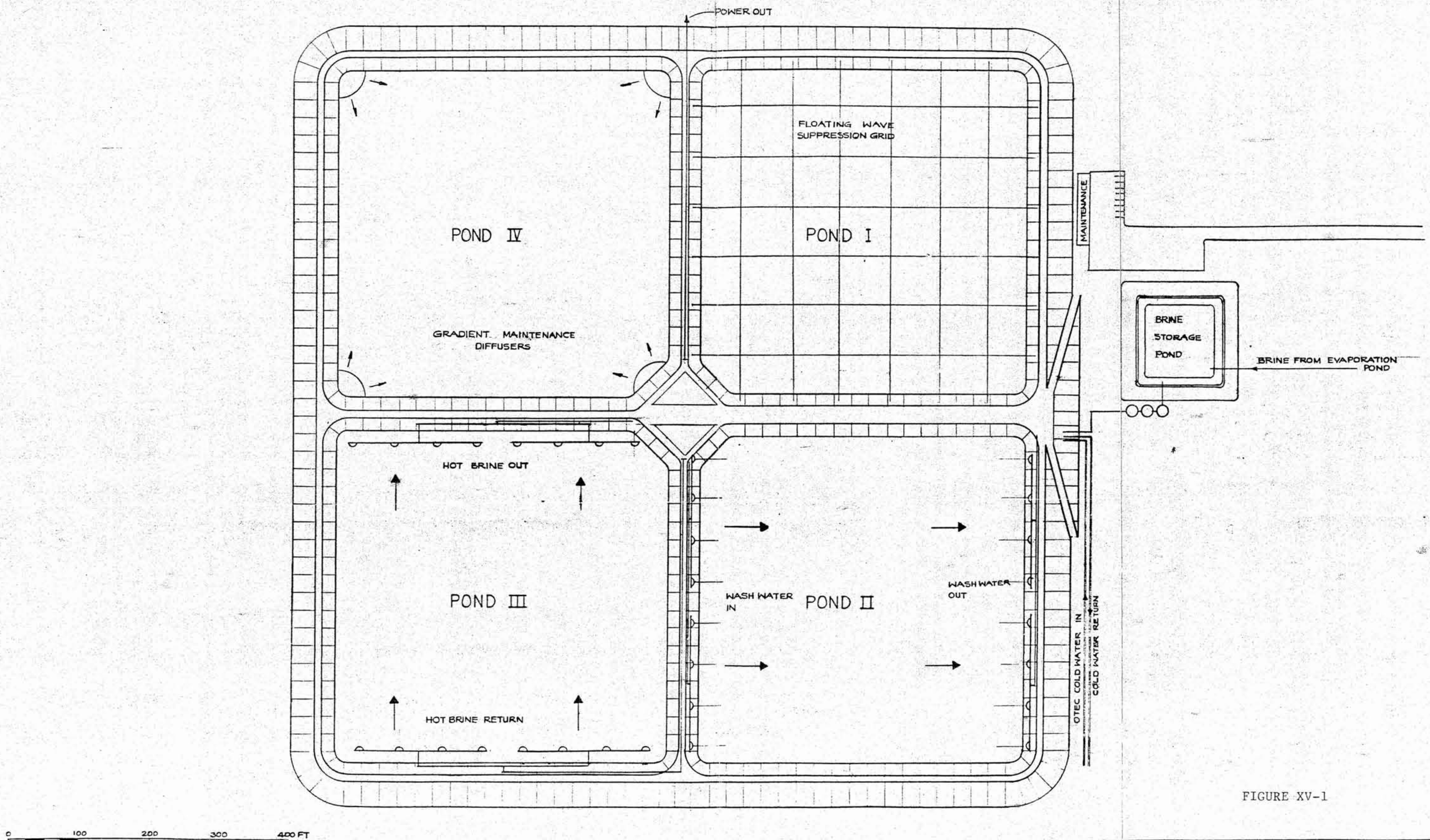
Two clusters of four nozzles each will be positioned near the center of each cell the clusters will be supported on a simple PVC structure placing the nozzles 10 feet above the surface of the brine. The spray height will be eight feet resulting in an 18 foot drop of the spray. The clusters will be fed through a six inch pipe by a diesel driven pump.

The brine intake to the pump is a perforated pipe lying on the bottom of the cell along the embankment. This arrangement is intended to take maximum advantage of any heating of the brine that may occur away from the spray nozzles.

E. Brine Spray Budget

Equipment for 1 cell:

Plumbing	$ 1,630
Supports	300
Nozzles	1,600



4 PONDS EACH 5 ACRES AND SHOWING DIFFERENT COMPONENTS FOR CLARITY

FIGURE XV-1

CONCEPT FOR KEAHOLE AIRPORT

SETS Inc.

Scientific, Educational, Technical Services

Honolulu, Hawaii

DWG NO. SHEET 1 OF 2

CKA-1

Pump and Engine	4,000
	$ 7,530
4 Systems	$30,120
Fuel	16,000
TOTAL for Spraying	$46,120

F. Salt Storage

Bulk salt is commonly stored unprotected in the open. At Ke-ahole where at most a few tons of salt will be stored at any one time, an area near the brine make-up facility has been identified as suitable for salt storage. A plastic or canvas tarp will reduce losses due to rain.

G. Brine Delivery

The brine delivery system consists of a brine line through which brine is pumped from the evaporation pond to the brine make-up and gradient make-up tanks. The pump is located at the evaporation pond on a concrete pad. A sand filter is provided by the make-up tanks.

XIV. OPERATION AND MAINTENANCE PLAN FOR THE BRINE PRODUCTION FACILITY

A. Passive Facility

The evaporation pond, as designed, is arranged in such a manner that by controlling the water level in each of the four cells, gravity flow will move the brine through the cells from the first with the incoming sea water to the fourth, from which the 22% brine is pumped. The flow between the cells is controlled by a valve which will be adjusted as required to maintain the proper brine level.

The predicted evaporation rate of 5.7 ft./yr. equals 11.4 acre ft./yr. or 496,584 cu.ft. of seawater, the pumping rate required to maintain the brine level therefore is approximately one cu.ft./min. or 7.5 GPM.

The initial filling to an average depth of 18" requires 13 days with a pumping rate of 60 GPM.

B. Active Facility

The spray equipment is placed in the passive pond. The pumping rate for the sea water supply increases to 45 GPM to meet the increased evaporation rate. The four diesel driven pumps will operate 24 hours a day at a total pumping rate of 1600 GPM. The valve settings should remain unchanged.

The manpower requirement for the spray operation is estimated to be 12 man days per month.

C. Maintenance

Passive Facility

The maintenance requirements for the passive facilitly are minimal. The low embankments are easily inspected and repaired. The two layers of liner have an expected life time in excess of 10 years. Leaks may be patched by lifting the liner out of the brine. Complete replacement can be accomplished by by-passing the affected cell and distributing the brine in the remaining cell.

In time precipitated salts, such as calcium sulphate, will cover the lining and interfere with the operation of the control valves. The valves are mounted on removable pipes for ease of handling for servicing. The supply pump requires periodic servicing as recommended by the manufacturer.

The manpower requirements are estimated to be two man days per month.

Active Facility

The maintenance requirements for the active facility are the same as for the passive with the addition of the daily maintenance of the diesel engines, periodic maintenance of the pumps and spray nozzles. The control of precipitated salts in pump seals and spray nozzles is the major concern. The man power requirements are estimated to be 12 man days per month.

XV. CONCEPTUAL DESIGN OF A 300 KWe SPOTEC POWER PLANT

A. Introduction

The concept presented here is based on the information gathered and calculations performed by SETS, Inc., during the past months design effort on the 15/30 KWe, plant to be located at the Natural Energy Laboratory at Ke-ahole Point, Island of Hawaii.

The exact location of this 300/600 KWe power plant cannot be determined at this time. The pond ideally would be close to the airport and to the cold water source and it would be on State land. It could be located on NELH land or airport land or partly on both. The site would be formally chosen presumably when the various State agencies to be involved define their roles. An example site is shown in Figure XV-1.

The average gross power output of the 15/30 KWe minimum facility wih a .5 acre bottom is 15 KWe. Direct scaling indicates that a pond with a 5 acre bottom and 2:1 interior embankment slope will produce 150 KWe.

The direct scaling is conservative since the percentage of heat loses through the peripheral embankment decreases with the increase in pond size. The pond volume increases at a faster rate than the peripheral embankments with a constant water level.

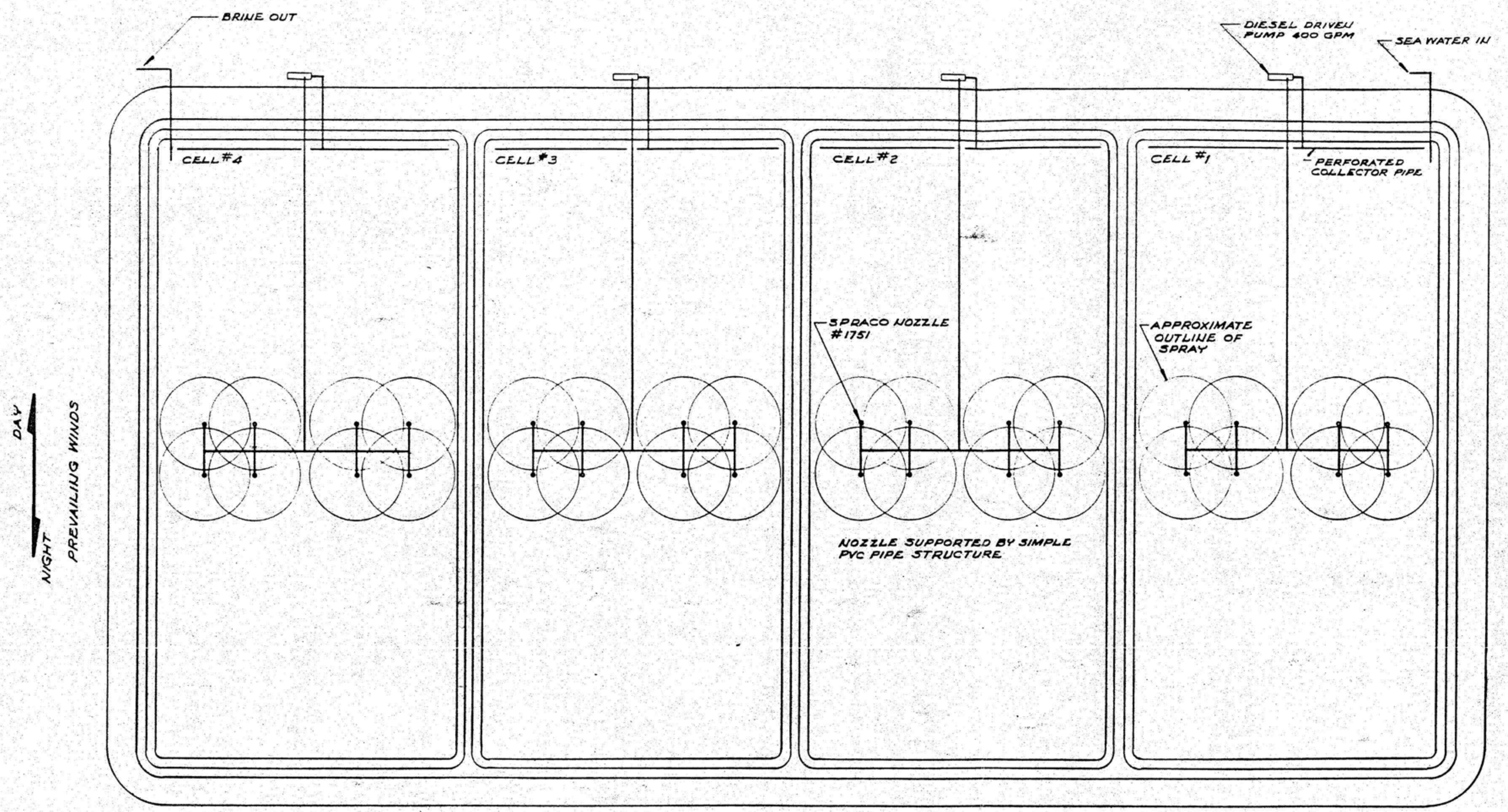
Because this facility is intended to meet the longterm energy needs of both Ke-ahole Airport and NELH, it seems desirable to design a facility which could be expanded easily beyond the minimum size. Therefore, the concept chosen here is a four five-acre bottom area module solar pond. Each module should produce about 150 KWe average power with its 5.44 acre collection area. Two of these modules (300 KWe) plus the first smaller (15/30 KWe) facility (15 KWe) would service the Ke-ahole Airport and NELH as they operate now (using about 60 + 215 = 275 KWe average; see Chapter V). A third module would provide contingency and for near-term future growth. The fourth module would be available for longer term growth, and for back-up and/or for storage of brine from another module for maintenance or emergency.

A number of arrangements of the modules have been investigated. Although there are no theoretical limits to the size of a pond, in this case where an artificial liner is required, a 5-acre bottom pond module provides a practical compromise from the point of view of liner installation, diffuser design and general maintenance.

One of the most important design considerations for a solar salt gradient pond is to keep the routing of the hot brine from the pond to the energy conversion equipment as short as possible. It is also desireable to place the pond as close as possible to the cold water source.

The first consideration can be controlled by the designer whereas the second is dependant on geography, topography and land ownership.

B. Pond Shape



ARRANGEMENT FOR MAXIMUM SPRAYING OF 1600 GPM

170 DAYS TO PRODUCE MINIMUM REQUIREMENTS FOR START-UP

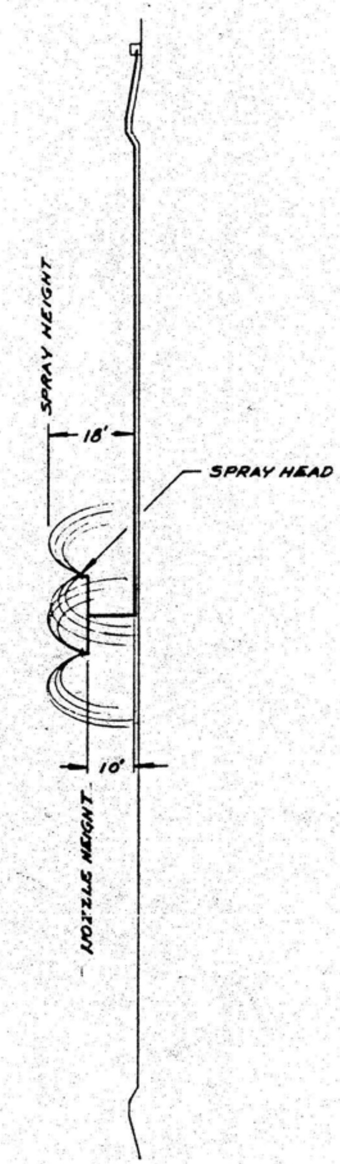


FIGURE XIII-1

KEAHOLE 1 ACRE 30KW SOLA SALT POND POWER PLANT		
BRINE MANUFACTURING ENHANCEMENT SCHEMATIC	SETS INC. Scientific, Educational, Technical Services Honolulu, Hawaii	SPOTEC 26

We propose a cluster of four, five-acre-bottom ponds surrounding a central island on which the energy conversion equipment will be located. (Figure XV-2).

A circular configuration divided into four-ponds was investigated. The circular peripheral embankment, by being shorter, minimizes the heat loss through the pond side. Although the circular embankment is shorter, the dividing spokes become longer reducing the potential material savings to about 5%. The added difficulty in constructing a circular embankment coupled with the necessary additional complications in the diffuser arrangements seem not to justify the relatively small savings in the construction costs.

C. General Arrangement

The four ponds surrounding the central island will each be designed to stand alone, i.e. each pond and energy conversion unit combination will be able to operate as an independent power plant. Cross connection piping will be provided for maximum flexibility in case of equipment failure. Under normal full operation the units will be ganged together in the electrical outputs only.

One of the internal embankments will be wide enough to support a twelve-foot-wide improved road bed. This road will serve as access to the central island. The cold water, surface wash water and the gradient maintenance water supply lines will be situated along the access road.

The area near the access road ramp will be occupied by the common services for the four ponds. A building of approximately 4,800 sq. ft. will contain administration office, maintenance facilities and general storage.

A brine storage pond and a make-up water facility with associated pumps will be located in this area in close proximity to the cold water and brine supply pipes.

D. Brine Production

For a solar salt gradient pond of this size, local brine production appears to be necessary. Forty thousand tons (43,750 tons) of salt or 146-acre ft. of 22% brine will be required for the complete four-module facility.

The present calculations for Ke-ahole Point give a salt production (in brine) rate of 1600 tons/acre/year (See Chapter XII).

We propose that a 10-acre brine production facility will provide sufficient brine for an incremental start-up of all four pond modules over a period of 2.7 years. Two of the five-acre bottom area modules could initially be dedicated to brine production. Thus, a minimum of a two-acre brine making facility would be required for maintenance during operation of the full plant.

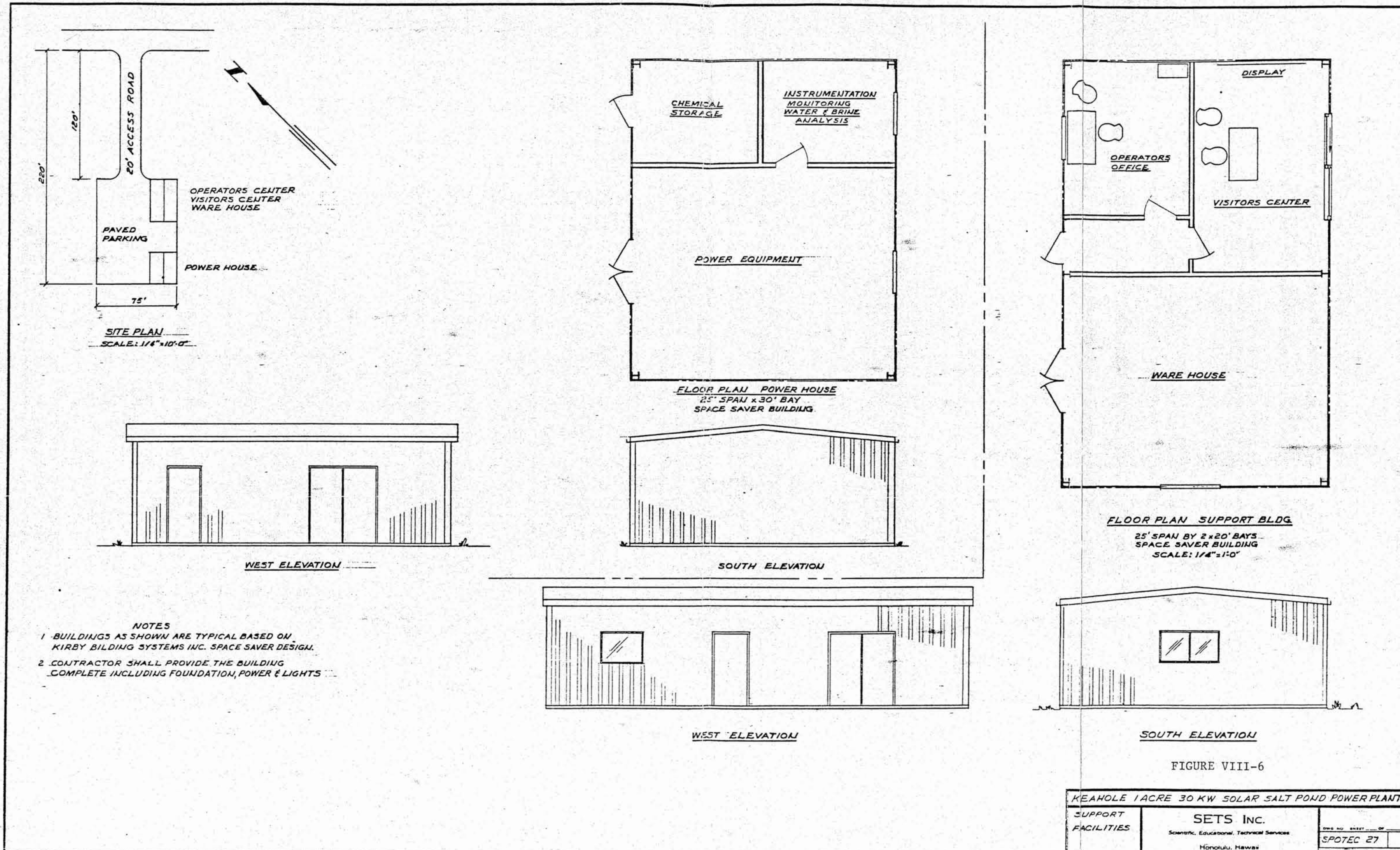


FIGURE VIII-6

E. Specifications

300/600 KWe SPOTEC Facility
(Approximate Numbers)

Total Land Area for Pond	28.5 acres
Material required for Embankments and Cushion Fill	447,147 cu.yd.
Liner Material Required	1,226,000 sq.ft.

WATER

Total Water Surface	980,504 sq.ft.
Surface Zone (1 ft.)	976,144 cu.ft.
Gradient Zone (4 ft.)	3,779,136 cu.ft.
Storage Zone (5 ft.)	4,474,580 cu.ft.

SALT GRADIENT

Surface Zone	1.59 lbs/cf	3%
Gradient Zone	Varies with Height Between 3% & 22%	
Storage Zone	13.75 lbs/cf	22%

SALT REQUIRED

Gradient Zone	12,991 tons
Storage Zone	30,762 tons

POWER FLOW RATES

Summer	Hot Brine, 22% salt, 95 degrees C @ 4000 GPM
Winter	Hot Brine, 22% salt, 95 degrees C @ 2000 GPM
Cold OTEC Seawater	3.5% salt, 12 degrees C @ 4000 GPM

POND MAINTENANCE FLOW RATES

Surface Evaporation Replacement	105 GPM
Migrated Salt Removal	44 GPM
Wash Water IN	149 GPM
Wash Water OUT	50 GPM

SALT MIGRATION

Inter Face Surface (Gradient to Surface)	9.64324 sq.ft.
Required Salt Return to Brine Circuit	9.4 lbs/M
22% Brine Return to Brine Circuit	6.2 GPM

XVI. CONSTRUCTION PLAN FOR 300 KWe SPOTEC POWER PLANT

The construction plan presented here (Figure XVI-1) is to bring into operation the full four-module facility and to show the best path to producing some electricity as quickly as possible. The modular design allows a variety of approaches some of which may be more economically and/or financially attractive than the one shown here. The time span before construction may take place makes detailed economic analysis meaningless at this time. Also, the power production capacity needed at the time of construction may dictate a less aggressive schedule.

This plan is based on the premise that all the brine needed will be produced by spraying in the power ponds and that the brine needed for maintenance will be produced in the original two-acre evaporation pond or in an unused module, with spray assist.

The project schedule shows that a general contractor could complete all the construction work required in 18 months. The maintenance and operations crew could start work at the beginning of Month #7 after the start of the project. The initial main task of this crew will be to participate in the liner installation and to install and operate the spray equipment.

The liner in the first pond will be installed at the beginning of Month #8 immediately followed by the installation of the spraying equipment and the beginning of the spraying operation.

Spraying should start in the remaining three ponds at approximately one month intervals.

A conservative estimate for brine production predicts that pumping 800 GPM per acre through the spray nozzles will produce 96,853 cu. ft. of 22% brine per acre per month.

Each five-acre pond requires a minimum brine depth of five feet and an additional two feet of depth for full capacity. These depths for a five acre pond translates to 1,143,579 cu.ft. and 447,458 cu.ft. respectively. Pumping 4,000 GPM in the five acre pond should produce the first five feet of brine in 12 months and the remaining two feet in an additional 4.6 months.

As the ponds begin to produce brine, the brine is transferred to Pond #1. When Pond #1 is full, Pond #2 starts filling and so on. By Month #13 after the start of construction, the brine level in this pond should be sufficient to establish the gradient layer and begin the warm-up process. By Month #14 the full complement of brine should have been inserted in the pond and by Month #19 sufficient brine temperature should have been achieved so electricity production at full capacity of the first 5-acre module could begin.

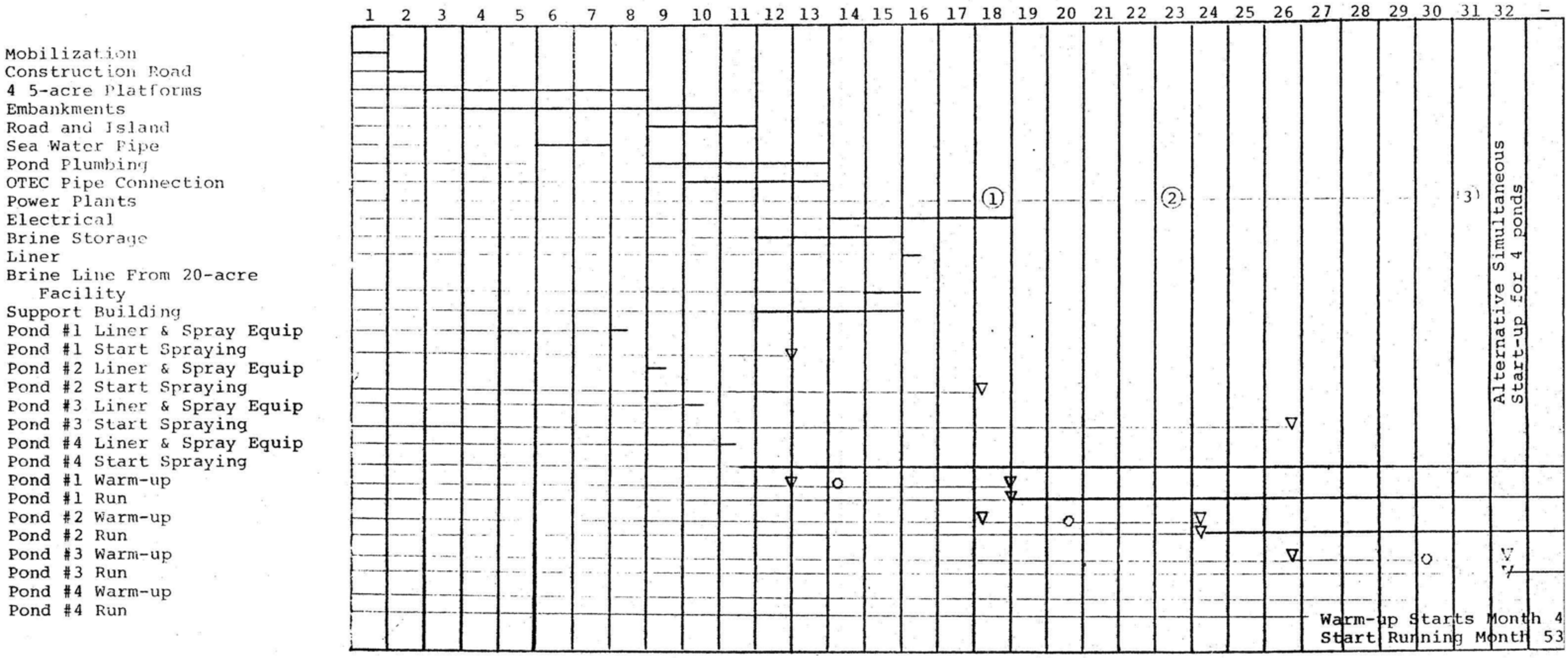
Pond #2 should be operational by Month #24, Pond #3 by Month #32 and Pond #4 by Month #53. If a decision is made to start all four ponds simultaneously it should be possible to have a full-up power plant by Month #30.

The individual time intervals given above may change some during the contemplated 52 month schedule. The time of the year when construction starts and the weather obviously will influence the details, but the overall time span is achievable.

Aside from the public relations and perhaps financial benefits gained by early power production the sequential start provides the opportunity to benefit from the experience with the early ponds and to apply this experience to improving the later ponds. Thus, this conceptual design has this approach as its baseline.

Figure XVI-1.

300 KWe Solar Salt Gradient Pond Power Plant and Associated Facilities Project Schedule



XVII. CONSTRUCTION BUDGET ESTIMATE FOR 300-600 KWE SPOTEC POWER PLANT

The estimated cost for constructing a 300-600 KWe SPOTEC power plant is presented in Table XVII-1. Two basic options are costed: (1) a minimum facility to produce 260 KWe average gross power and 600 KWe peak power, and (2) a larger facility producing 520 KWe average gross power. These cost estimates are in spring 1983 dollars and include all expected costs except taxes.

The costs would be spread over five years and could be spread over a longer period without significant extra cost (except inflation).

There are additional design options available which will affect costs. For example, pond sizes other than the options chosen here could be built.

Table XVII-1

COST

260 KWe	2 Modules 10' Pond/12' Embankmant 2:1 x 2:1
Pond Civil Work	$1,200 thousand
Power Plant (2 x 100 KVA)	250
Liner	380
Plumbing	700
Pumps	35
Diffusers	20
Building	100
Electrical	250
Instrumentation	70
Miscellaneous Equipment	50
In-house Construction Crew	50
	$3,105
Engineering Design Construction Management	300
Salt Manufacturing	$ 600
	$4,005 thousand

Table XVII-1 (Cont.)

520 KWe	4 Modules 10' Pond/12' Embankment 1 1/2:1 x 3:1	
Pond Civil Work	$3,000	thousand
Power Plant (4 x 100 KVA)	505	
Liner	700	
Plumbing	1,200	
Pumps	70	
Diffuser	20	
Building	100	
Electrical	300	
Instrumentation	190	
Wave Suppression Grid	190	
Miscellaneous Equipment	50	
In-house Construction Crew	60	
	$6,285	
Engineering Design Construction Management	250	
Salt Manufacturing	1,192	
	$7,727	thousand

XVIII. START-UP AND OPERATION PLAN FOR THE 300 KWe SPOTEC POWER PLANT

A. Introduction

The 300 KWe SPOTEC power plant is divided into four five-acre bottom-size modules. The design depth of these ponds is 10 feet, divided into three zones. The bottom or storage zone contains 22% brine and is five feet deep. The intermediate or gradient zone contains carefully constructed layers of brine with a salt content of 22% at the lower layer and 3.5% at the upper layer. This zone is four feet deep. The top zone is about one foot deep.

The design depth of five feet for the storage zone is a compromise arrived at by an evaluation of economic constraints and the available solar energy profile. The ponds will function, however, at a reduced output with as little as three feet of brine in the storage zone. The gradient zone of four feet requires two feet of brine before stratification by mixing with two feet of seawater. Thus, when five feet of brine are available, the establishment of the gradient zone can begin.

B. Start-up

The establishment of the gradient zone follows the pattern set for the 15/30 KWe plant (see chapter XI). Four diffusers delivering a total of 312 GPM for each of the four five-acre ponds are proposed to insure even distribution. The schedule for gradient zone establishment should follow that for the one-acre pond but lengthened by the ratio of 5/4. With the gradient zone established, the warm-up phase begins. The length of time required for the brine temperature to rise from ambient to 200 degrees F when energy extraction can occur is dependant on several variables, as described for the 15/30 KWe facility, but the nominal time is six months.

C. Operation

It is planned to fully automate the four ponds. The instrumentation network will feed information to a central computer on the status of the pertinent parameters (fluid levels, temperature, clarity, etc.) and then control the valves and pumps to enable the power plant to deliver the maximum power possible under the changing climatological conditions. Some maintenance personnel will be required under any circumstance. To handle the physical maintenance of the plumbing, the heat exchangers, the electricity generating equipment, computer-related electronics, etc. A staff of three is envisioned.

It appears practical to use the original two-acre evaporation pond as a source for make-up brine. The spray enhancement equipment would be powered by electricity from the power plant. Alternatively, the evaporation pond could be enlarged to about four acres and only passive evaporation used.

D. Damage Control

The major danger is a leak in the pond and loss of the brine and stored energy. By maintaining a two-foot freeboard in the ponds all the storage zone brine from one pond may be transfesrrerd to the other three. Thus, in case it becomes necesssary to empty one pond, neither the brine nor the stored energy would be lost.

Heavy storms with high winds could increase the depth of the upper or surface zone due to wave action in spite of the wave-suppression system. This would decrease the efficiency of solar energy conversion but use of the gradient maintanence equipment would easily repair the upper gradient zone.

XIX. PUBLIC INFORMATION PLAN

A. Introduction

Several persons and agencies including Mr. John P. Keppeler, III, Mr. Jai Wai, the Hawaii District Office, State Department of Education were contacted regarding this plan. They offered suggestions of the groups they felt needed to be included in an information dissemination program regarding the SPOTEC development program. Those listed most frequently as important to include in information sessions are the Charter Fisherman's Association, the Kona Outdoor Circles and West Hawaii Today. The Konawaena High School science club was suggested as a youth group which is active in promoting Big Island science and technology interests.

There are a number of organizations, civic groups, governmental agencies, and educational organizations that should be made aware of the development of the SPOTEC power plant at Ke-ahole. Since the nature of these groups is quite diverse the nature of the informational presentations also needs to be varied. The information format should include the holding of meetings, formal presentations and the availability of written information regarding the nature of the proposed project.

Contact Groups

There are several different types of groups, agencies and institutions that should be made aware of the proposed project. These can be clustered into categories as presented here:

Educational Institutions:
- University of Hawaii, Hilo, Continuing Education
- Hawaii Science Teachers Association
- High School Science Clubs,
  (Particularly those at Hawaii Preparatory Academy, Kanowana High School, these are active groups interested in Big Island science activities.)
- Chamber of Commerce
- West Hawaii Committee

Civic:
- Kona Lions Club (Mauka, Makai)
- Kona Kiwanis (Mauka, Makai)
- Kona Rotary (Mauka, Makai)
- Civitan (Kona service club)
- Kona Outdoor Circle (very concerned about asthetics and environmental impacts of projects on the Kona coast)

Clubs:
- Charter Fishermans Association

The commercial and community fishing groups throughout the Big Island and particularly in Kona should be apprised of the project as they are most concerned about any project that is perceived as impacting on the areas fishing grounds. Reassurance needs to be given that there will be no adverse effects and no harmful discharge into the ocean from the development or operation of a SPOTEC power plant.

The local media such as West Hawaii Today needs to be informed of the proposed project and educated as to the nature of the project and given information from which informative articles can be developed and published.

The education and information dissemination efforts should not be limited to West Hawaii but should also include all residents of the island. Hilo and Waimea have several business and service groups at which presentations should be made.

Information

There should be a series of "fact sheets" or informational brochures developed that can be handed out to answer the basic questions of the nature of a solar pond, how a pond produces power, the economics of solar pond and SPOTEC power plants and the environmental impact of the facility at the Ke-ahole site (see attachments for examples). A slide presentation, with tape or script, could also be easily developed to answer these questions and be used for presentations to the different civic and educational institutions. These materials need to be able to stand on their own, i.e., there should be no need for an interpreter or person to interpret everything that was presented.

Display areas such as those at NELH and the Kona Library should be utilized to present illustrations, drawings, etc. of the proposed project. It is important that people be able to visualize how the facility fits into the area environment. These displays might also include the SPOTEC power plant "fact sheets".

WHO?

SETS, Inc. is a private Hawaii corporation based in Honolulu.

SETS, Inc. provides moderate and high technology services and goods in Pacific Oceania in the areas of engineering, science, education and technology in general.

SETS, Inc. makes available to public, private, state, national and international groups the spectrum of expertise represented in SETS, Inc. and in the public and private sectors of the State of Hawaii and the Mainland U.S.

SETS, INC.

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1110 University Avenue
Honolulu, HAWAII 96826

(808) 942-8712
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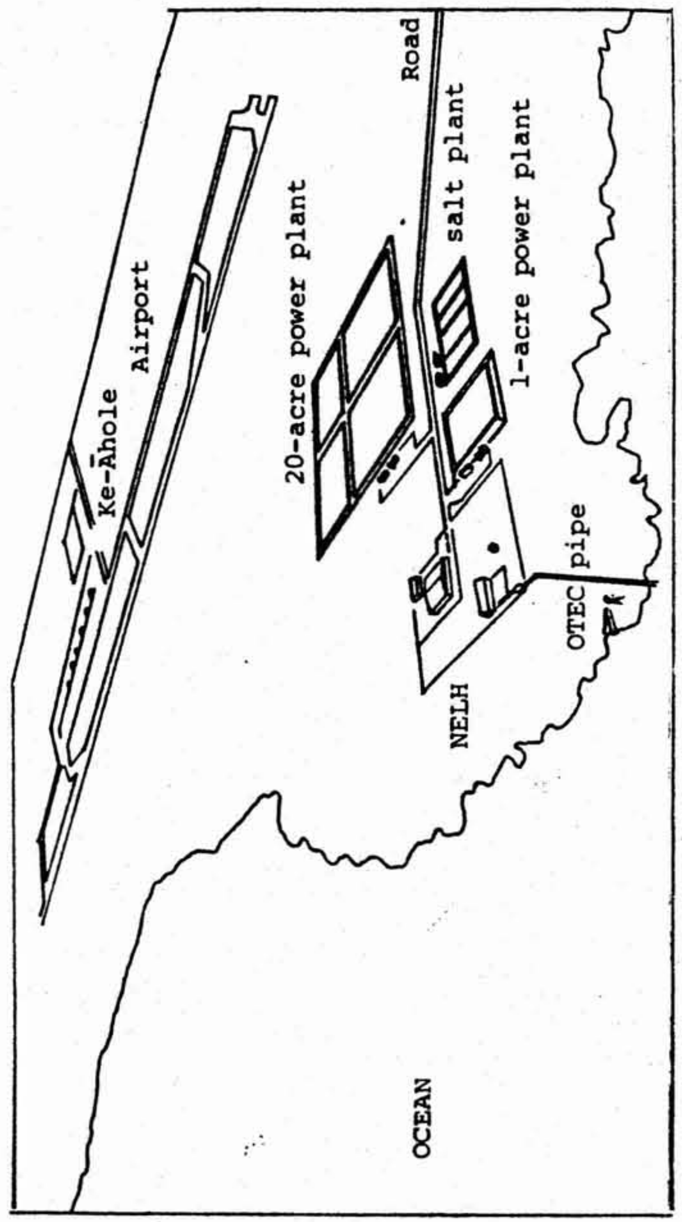


SOLAR POND POWER

FOR

HAWAII

AND THE

PACIFIC

THE KE-ĀHOLE SPOTEC

POWER PLANT PROJECT

WHAT IS A SOLAR POND?

A solar pond is a body of water that collects sunlight and stores it as heat. This thermal energy (heat) can then be used for many things...including the generation of electricity.

The sun provides the heat, which is stored in the heavy very salty water at the bottom of the pond. On the top of the heavy salt water is a layer of lighter, fresher water (e.g. sea water). The hot salt water is too heavy to rise and the heat is stored. The hot water from the pond is pumped through a heat exchanger to vaporize a working fluid to turn a turbine wheel and the electric generator linked to it. In Hawaii the cold water from the OTEC deep ocean pipe can be used to turn the vapor back to a liquid so the process can start all over again.

This is the same cycle used in OTEC. The approach can be thought of as solar-assisted OTEC or as OTEC-assisted solar ponds. We call it SPOTEC.

The unique feature of the Hawaii project is the combination of OTEC and solar pond technologies to improve both.

SOLAR PONDS CAN PROVIDE STABLE LOW COST POWER FOR SPECIFIC NEEDS LIKE VILLAGES AND AIRPORTS OR FOR THE GRID.

WHY HAWAII?

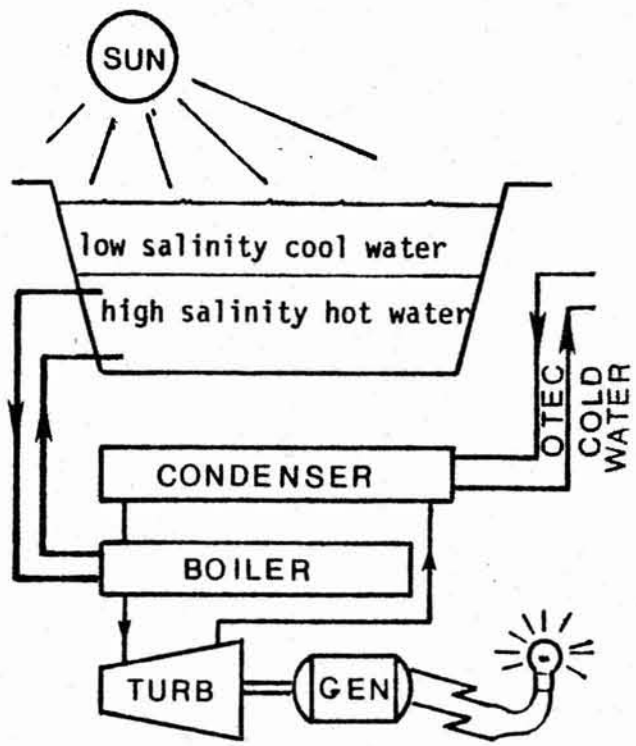
Hawaii and other Pacific islands are favorable natural settings for solar pond power plants.

SUN

SALT

WATER

A NEED FOR POWER



SOLAR PONDS PROVIDE FIRM POWER 24 HOURS/DAY, 365 DAYS/YEAR

THE HAWAII SPOTEC PROJECT AS AN EXAMPLE

The GOAL:

DEVELOP A SPOTEC POWER PLANT TO POWER THE KE-AHOLE AIRPORT AND THE NATURAL ENERGY LABORATORY ON THE ISLAND OF HAWAII

The OBJECTIVES:

1) Develop a stable, low cost, secure power source for the airport and laboratory as a model for other applications.
2) Develop solar pond power plants as a form of OTEC using deep ocean cold water with the hot pond water.
3) Develop Hawaii's expertise in building solar pond power plants as hi-tech industry and for export to its Pacific island neighbors.
4) Develop Hawaii's reputation in the Pacific Basin as a source of expertise and experience in energy and other technologies.

Project support so far has been by Hawaii Department of Planning and Economic Development. It could be carried out at the Natural Energy Laboratory of Hawaii.

THE HEAT CAN BE USED FOR INDUSTRIAL PROCESSES, TO MAKE MECHANICAL ENERGY AND TO MAKE ELECTRICITY.

A Possible DEVELOPMENT SEQUEN

Design of the plant--finish
June 1983

Construction of first modul
begin fall 1983

Operation and testing--begi
winter 1984

Finish design of complete
plant--fall 1985

Construction of complete
plant--fall 1985

Routine operations--1988.

The SCOPE:

The First Module will be--
15 KWe firm power
(24 hrs/dy)
30 KWe peak power
130,000 KWH/yr

The Complete Plant will be-
300-600 KWe firm power

THE PROJECT WILL PROVIDE COMMERCIAL AMOUNTS OF FIRM POWER WHICH COULD BE TRADED OR SOLD.

EXAMPLE

FACT SHEET

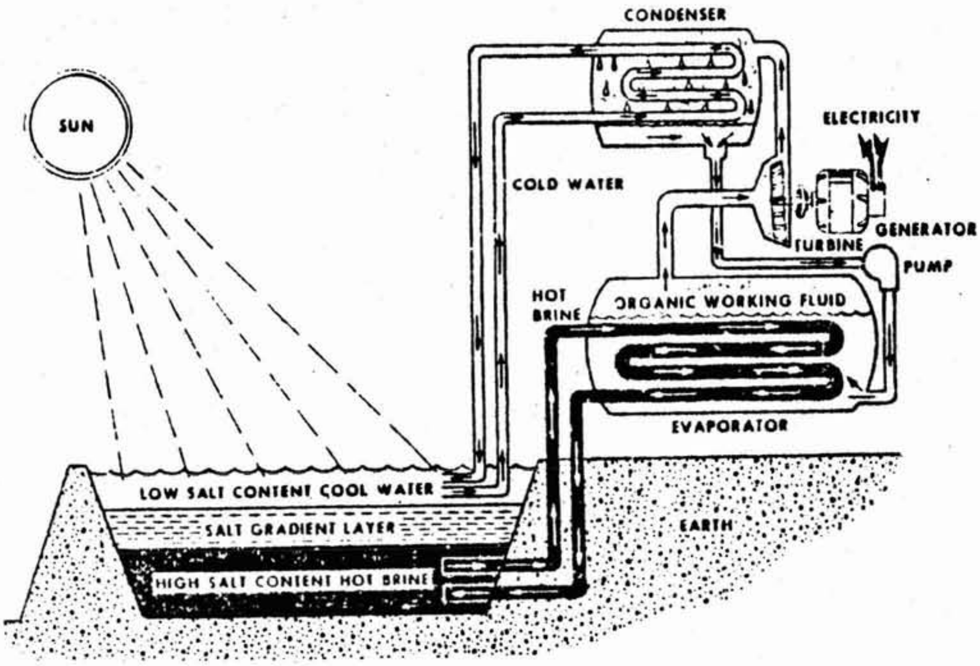
WHAT IS A SOLAR POND ?

The solar pond is a practical and natural way of using solar energy to make electricity. The use of solar ponds to produce electricity is one form of alternative energy, that is, producing energy without depending on oil or use of fossil fuels.

The solar pond is a body of water that collects sunlight and stores this light in the form of heat. This thermal energy (heat) can then be used for many things....including the generation of electricity.

In a solar pond used for making electricty the SUN provides the HEAT. The HEAT is stored in the heavy very SALTY WATER at the BOTTOM of the POND. On the TOP of this salty water is a layer of lighter COLD FRESHER water. The HOT SALT WATER is too heavy to rise and HEAT is STORED in this water. The HOT SALT WATER is PUMPED through a HEAT EXCHANGER to vaporize a working fluid to TURN a TURBINE WHEEL and the ELECTRICAL GENERATOR linked to it. The COLD FRESHER WATER is used to turn the VAPOR back to a LIQUID so the process can START AGAIN.

SOLAR PONDS PROVIDE FIRM POWER
24 HOURS/DAY, 365 DAYS/ YEAR



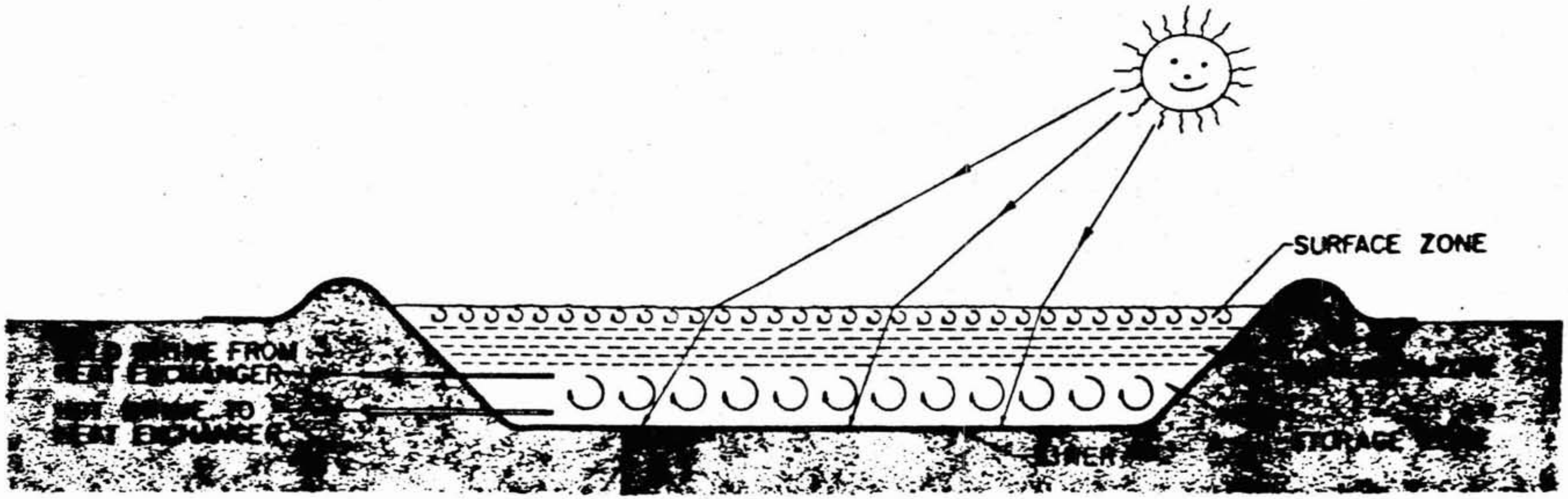
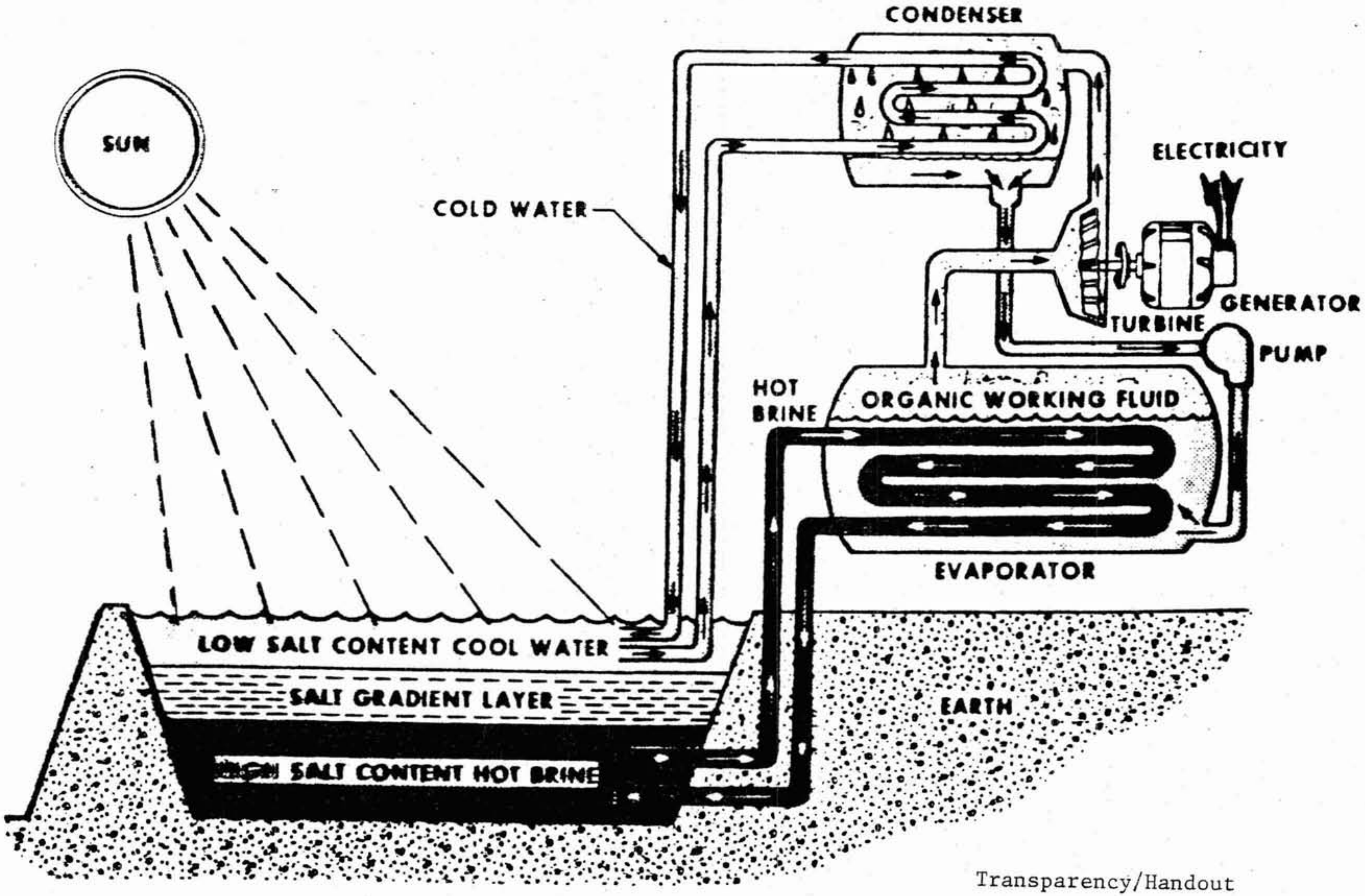
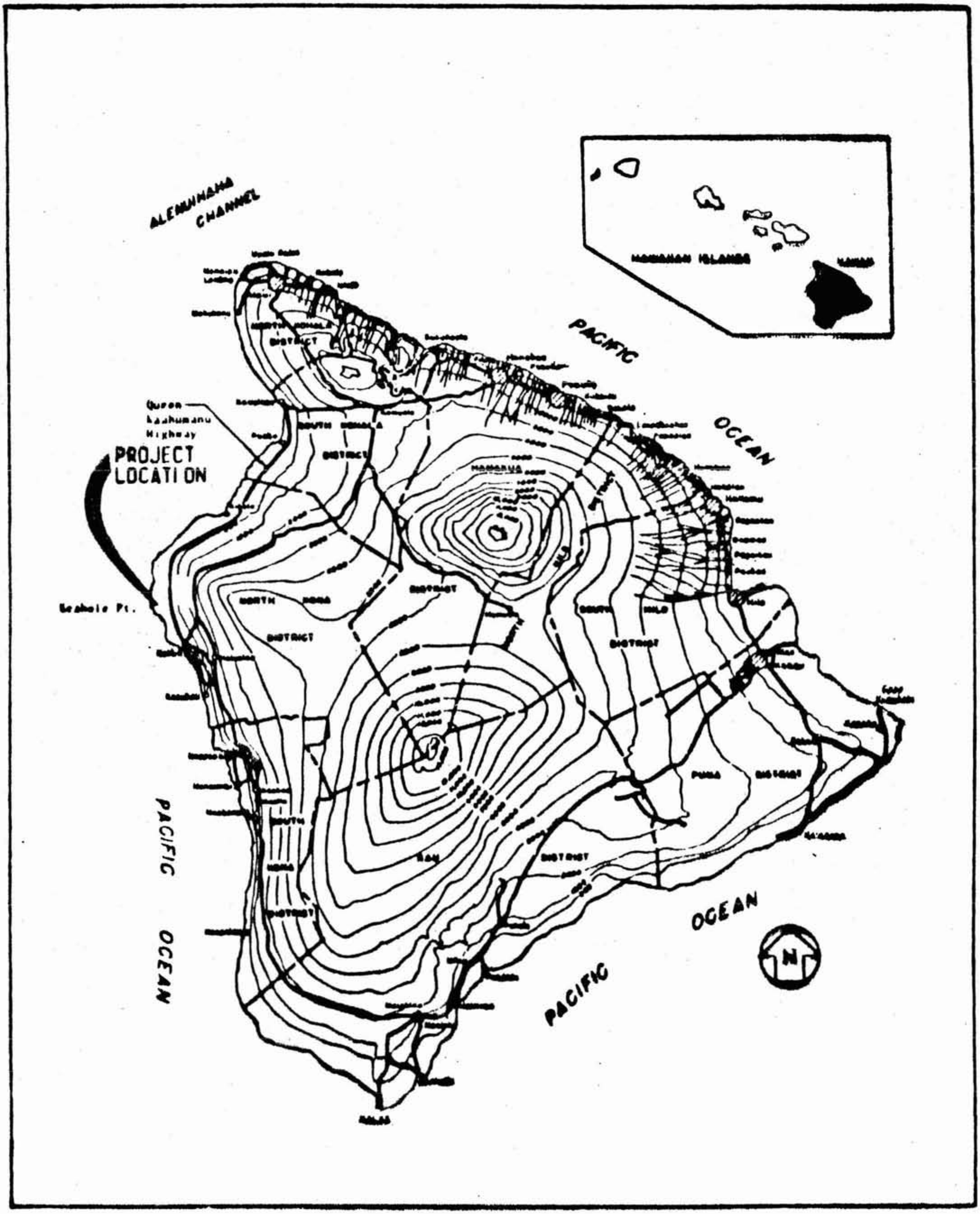


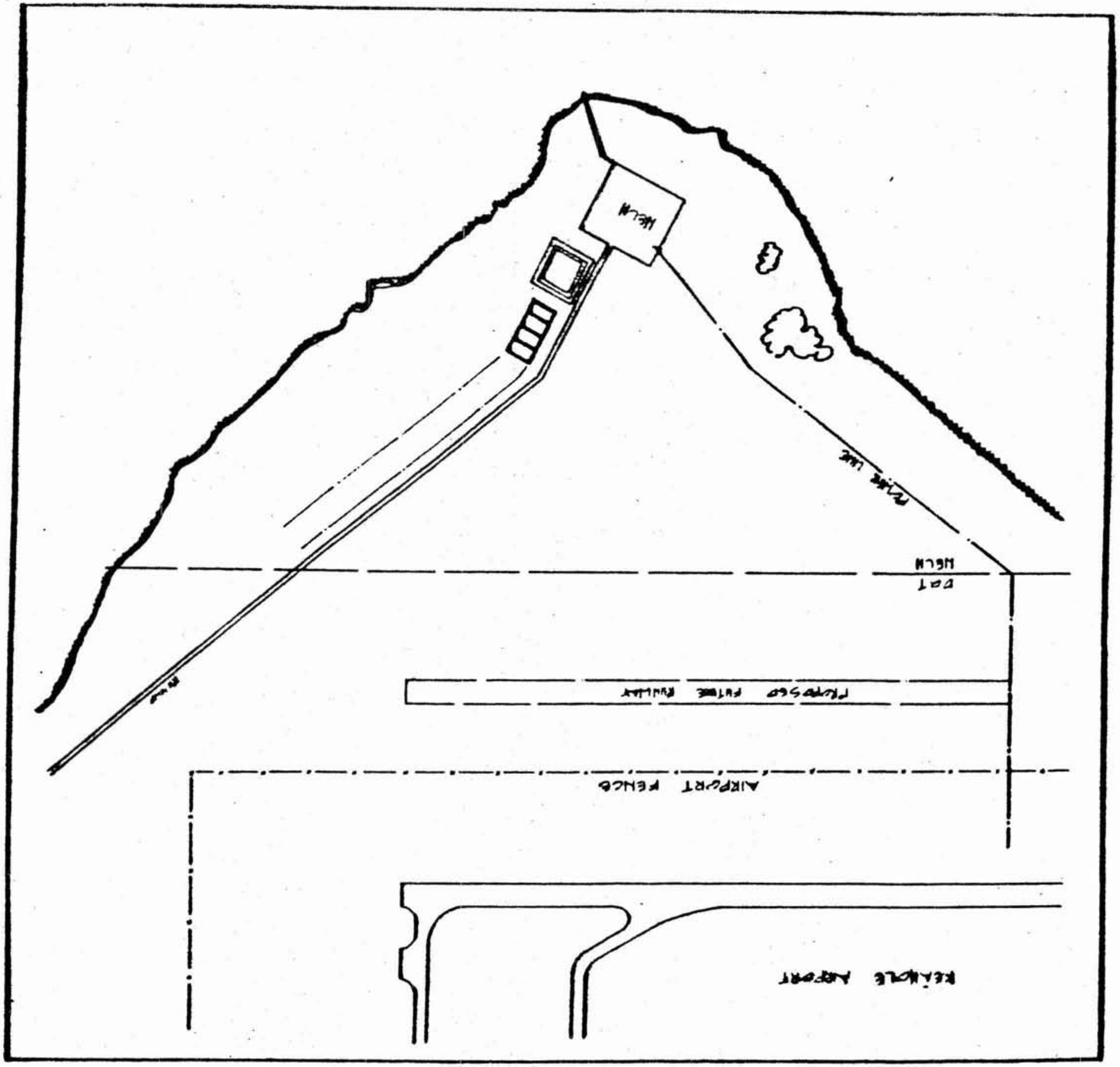
Fig. 1. Configuration of a Salt Gradient Solar Pond



Transparency/Handout

Transparency/Handout





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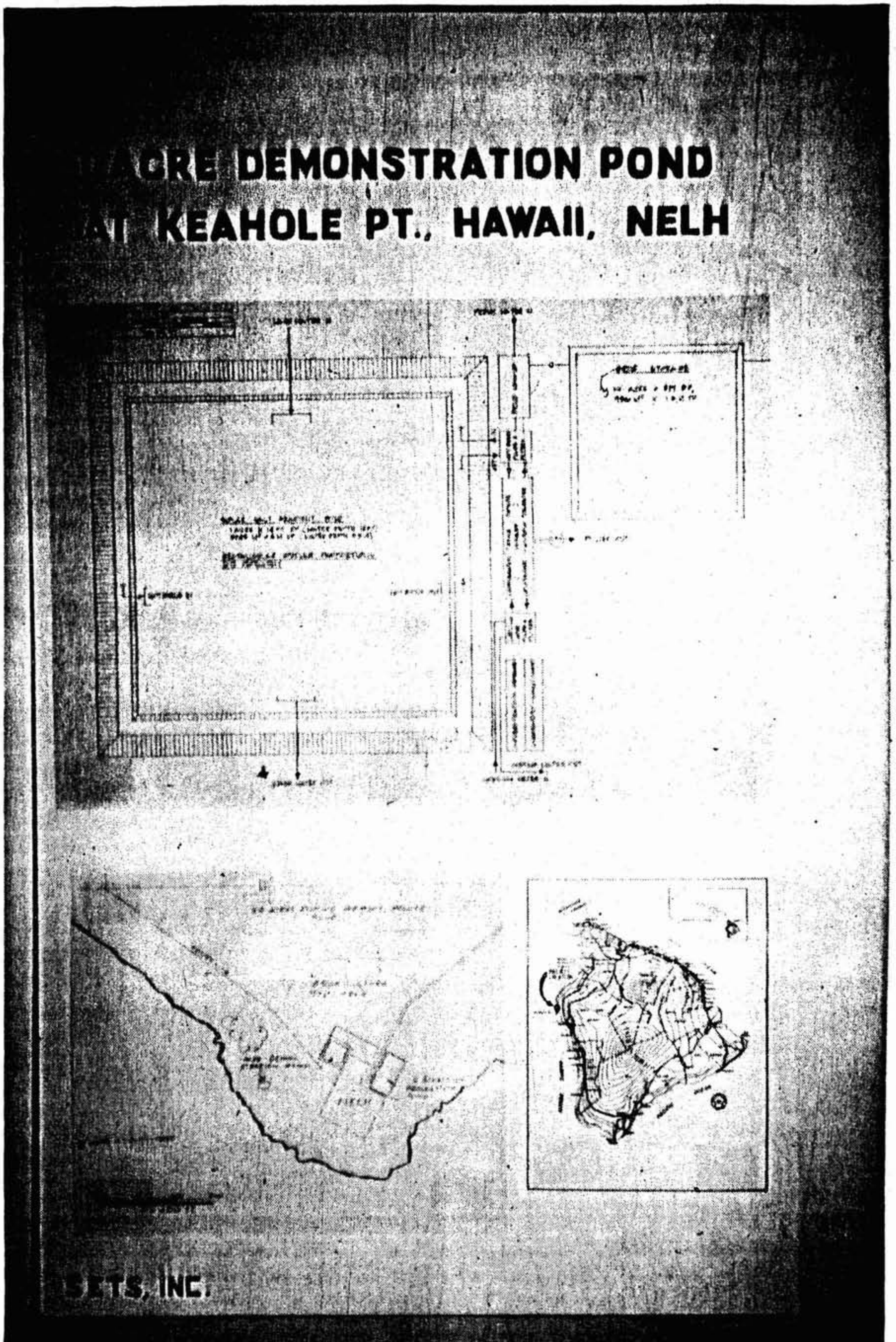
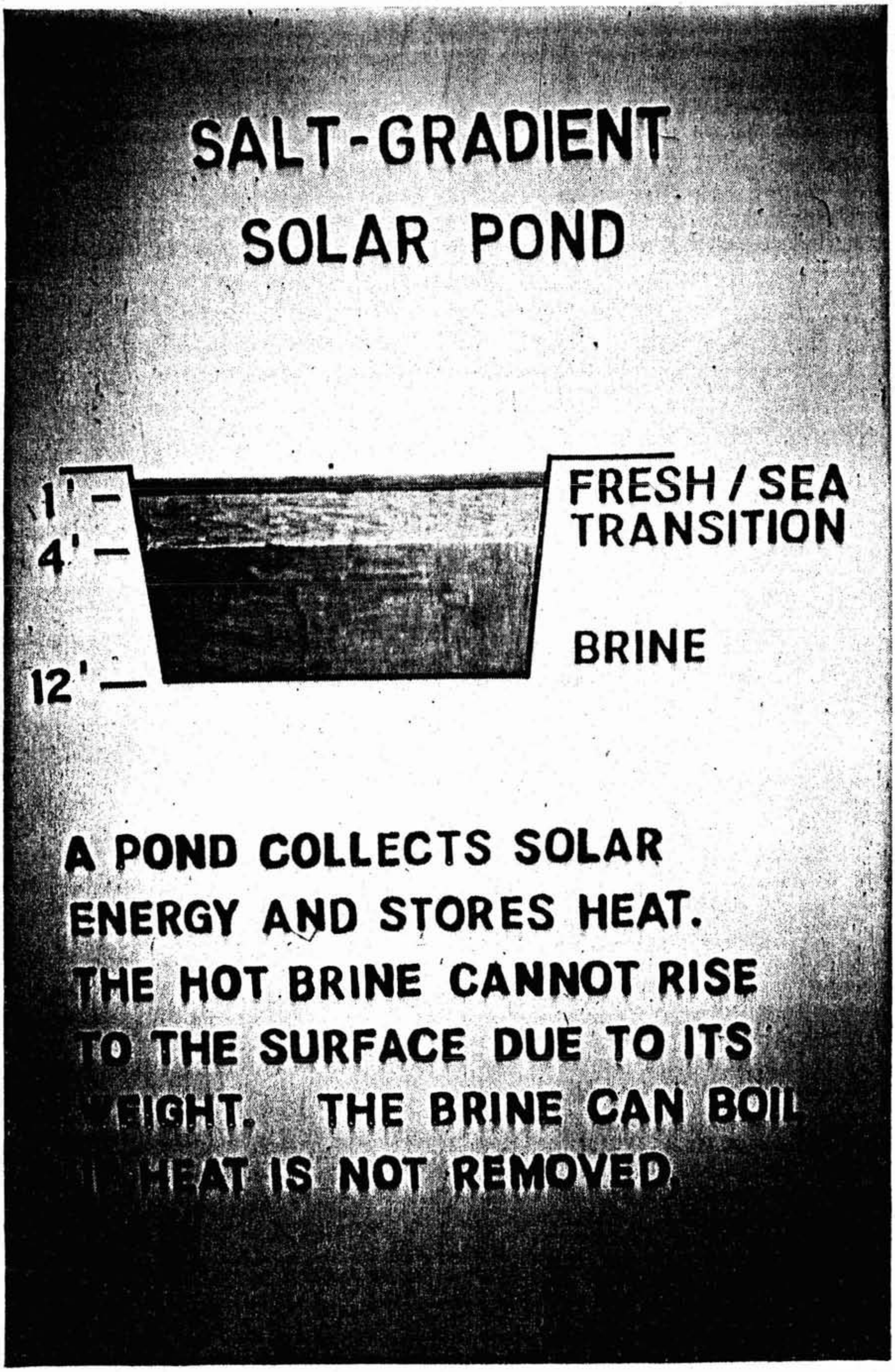
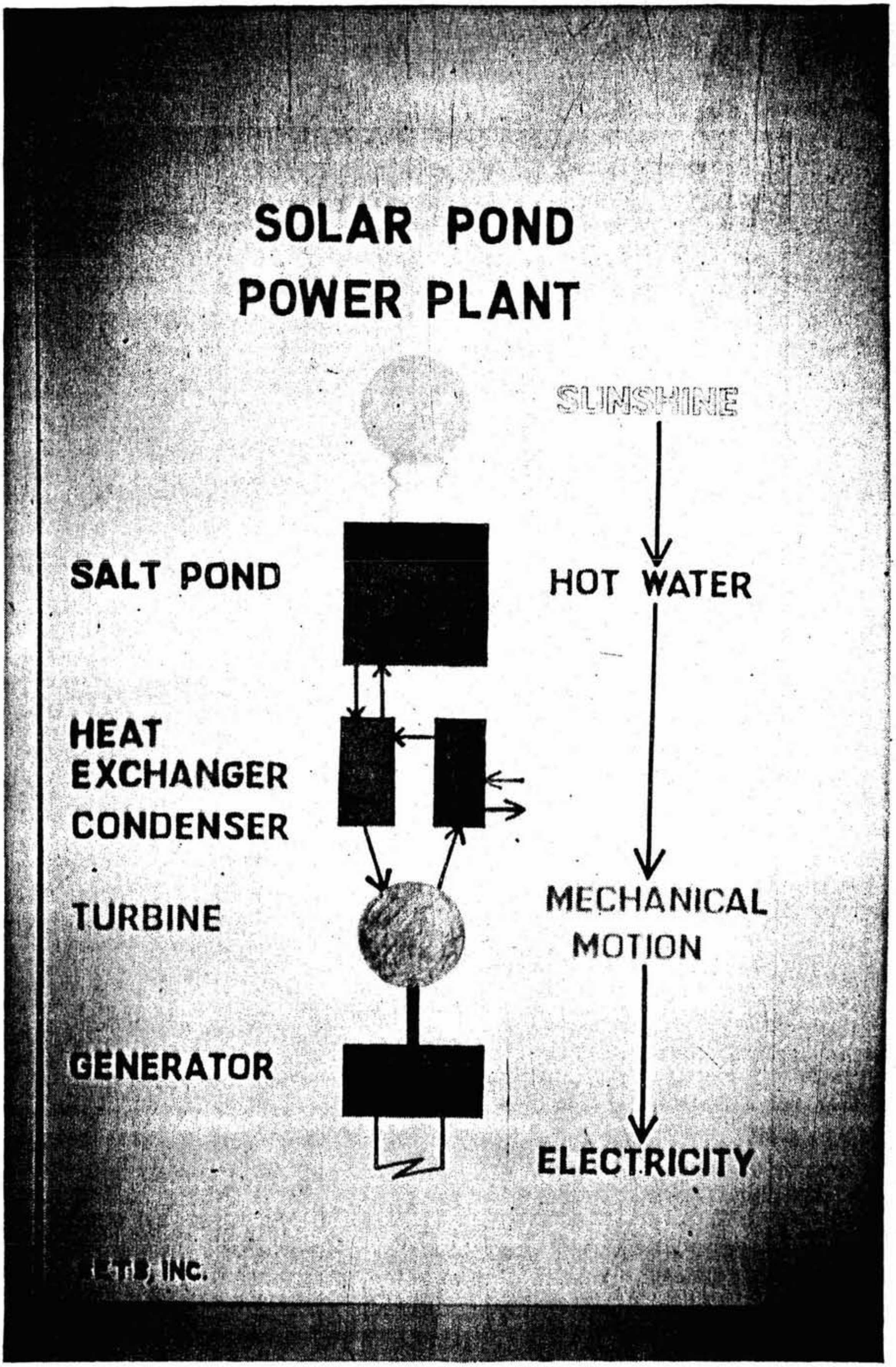

DEMONSTRATION POND
KEAHOLE PT., HAWAII, NELH
INC.


SALT-GRADIENT
SOLAR POND
1'
4'
12'
FRESH / SEA
TRANSITION
BRINE
A POND COLLECTS SOLAR
ENERGY AND STORES HEAT.
THE HOT BRINE CANNOT RISE
TO THE SURFACE DUE TO ITS
WEIGHT. THE BRINE CAN BOIL
HEAT IS NOT REMOVED.


SOLAR POND
POWER PLANT
SUNSHINE
SALT POND
HOT WATER
HEAT
EXCHANGER
CONDENSER
TURBINE
MECHANICAL
MOTION
GENERATOR
ELECTRICITY
INC.

SOLAR POND
POWER GENERATION
ECONOMICS

TO GENERATE FIRM ELECTRICAL
POWER 24 HR/DAY, ALL YEAR
REGARDLESS OF WEATHER

SOLAR POND
POWER GENERATION
ECONOMICS

TO GENERATE FIRM ELECTRICAL POWER 24 HR/DAY, ALL YEAR REGARDLESS OF WEATHER

COSTS

	BUILD per KW	OPERATE per KWh
SMALL PLANT	$10-15K	$.05
LARGE PLANT	$3-6K	$.03

XX. ACKNOWLEDGEMENTS

A large number of organizations and individuals have contributed to this engineering design and held informative dialogues with members of the SPOTEC design team.

Among the subcontractors, the Jet Propulsion Laboratory (JPL) solar pond project technical and managerial staff were particularly cooperative and assisted with SETS, Inc. efforts in obtaining up-to-date technological information. Mr. Chester Jenkins was particularly generous with his time and expertise. This was particularly appreciated since there is an extremely limited amount of written material regarding salt production and salt purchases.

The staff of NELH and Dr. Tom Daniel contributed much in terms of assistance in obtaining needed site information and facilitated site team visits.

Mr. Chuck Fankboner generously communicated the wisdom and expertise that comes with familiarity of the Ke-ahole site regarding the civil engineering and construction considerations.

The SPS personnel were particularly understanding and helpful regarding their turbine experience and providing time and expertise beyond the scope of need, particularly when considering the nature and scope of this proposed project.

XXI. BIBLIOGRAPHY

Chapter 2

Lin, E.I.H., A Review of the Salt-Gradient Solar Pond Technology, DOE/SF-11552-1, Jet Propulsion Laboratory, California Institute of Technology, California, January, 1982.

Lin, E.I.H., French, R.L., Singer, M.J., Wu, Y.C., McMurrin, J.C., Barbieri, R.H., Walton, A.L., Jones, S.C., Hurick, M.G., Levine, N., and Richter, P.H., Regional Applicability and Potential of Salt-Gradient Solar Ponds in the United States, Vol II: Detailed Report, DOE/JPL-1060-50, Jet Propulsion Laboratory, California Institute of Technology, California, March, 1982.

McCord, T.B., Bathen, K.H., Boesgaard, H., Fanale, F.P., McCord, S.C., Scudder, R.J., Weeks, D.D., and Yuen, J.W.L., Suitability of Salt-Gradient Solar Ponds for Electrical Power Generation in the U.S. Trust Territory of the Pacific Islands, Guam and American Samoa, Report by SETS, Inc. submitted to the U.S. Department of Energy, November, 1982.

Solar Pond/SPOTEC Alternate Energy Contract with Department of Planning and Economic Development, 1982.

Chapter 3

Bathen, K.H., et al., An Evaluation of Oceanographic and Socio-economic Aspects of a Nearshore Ocean Thermal Energy Conversion Pilot Plant in Sub-tropical Hawaiian Waters, Final Report prepared for the National Science Foundation-RANN, Energy Research and Development Administration, 305 pp., 1975.

Krajina, Vladimir J., Biogeoclimatic zones on the Hawaiian Islands, Hawaiian Botanical Society Newsletter, 2(7):93-98, 1963.

The Natural Energy Laboratory of Hawaii, Policies and Procedures Manual, State of Hawaii, revised as of 2/24/82.

R.M. Towill Corporation, Revised Environmental Impact Statement for the Natural Energy Laboratory of Hawaii at Ke-ahole Point, Hawaii (Phase 1), prepared for the Research Corporation of the University of Hawaii, Honolulu, Hawaii, December 1976.

U.S. Department of Energy, Assistant Secretary for Environmental, Office of Environmental Compliance and Overview, Environmental Assessment Seacoast Test Facility-Stage, prepared with Assistance of Argonne National Laboratory, DOE/EA-0121, November 1980.

Rosendahl, P.H., Archaeological Research Associates, Intensive Archaeological Survey and Salvage Excavations at the Natural Energy Laboratory Hawaii (NELH) Site, Ke-ahole Point, North Kona, Hawaii Island, Final Report, prepared for the Research Corporation of the University of Hawaii, Pahoa, Hawaii, January 1980. Ms. 2-123179.

Rosendahl, P.H., and Kirch, P.V., Archaeological Reconnaissance Survey of the Ke-ahole Point Natural Energy Laboratory Site, North Koña, Hawaii Island, prepared for R.M. Towill Corporation, Honolulu-Dept. of Anthropology, Bernice P. Bishop Museum, November 1975. Ms. 111775 with appendix.

Chapter 4

Bathen, K.H., and Gupta, S., Preliminary Assessment of Solar Salinity Gradient Ponds Applications in Hawaii, Hawaii Natural Energy Institute, Univ. of Hawaii, Oct. 1980, HNEI-80-08.

How, K.T.S., Solar Radiation in Hawaii 1932-1975 Basic Data Release, Hawaiian Sugar Planters' Association for Division of Water and Land Development, Department of Land of Natural Resources, State of Hawaii, January 1978, Report R57.

R.M. Towill Corporation, Revised Environmental Impact Statement for the Natural Energy Laboratory of Hawaii at Ke-ahole Point, Hawaii (Phase 1), prepared for The Research Corporation of the University of Hawaii, Honolulu, Hawaii, December 1976.

Shaw, Samuel L., A History of Tropical Cyclones in the Central North Pacific and the Hawaiian Islands, 1832-1979, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, MD, September 1981.

State of Hawaii, Department of Land and Natural Resources, Division of Water and Land Development, Pan Evaporation in Hawaii 1894-1970, Honolulu, Hawaii, January 1973, Report R51.

U.S. Department of Energy, Assistant Secretary for Environment, Office of Environmental Compliance and Overview, Environmental Assessment Seacoast Test Facility-Stage, prepared with Assistance of Argonne National Laboratory, DOE/EA-0121, November 1980.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, Climate of Hawaii, Climatography of the United States No. 60, Asheville, NC, July 1978.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data and Information Service, National Climatic Center, Climatological Data Hawaii and Pacific, Asheville, NC, 1982.

Chapter 6

County of Hawaii, Central Coordinating Agency, Planning Department, Permit Register-County of Hawaii, Hilo, Hawaii, 1978..

Hawaii, State of, Aquaculture Planning Program, Department of Planning and Economic Development, Permits and Environmental Requirements for Aquaculture in Hawaii, June 1977.

Hawaii, Department of Planning and Economic Development, et al., Hawaii

Integrated Energy Assessment, Volume V, Rules, Regulations, Permits and Policies Affecting the Development of Alternative Energy Sources in Hawaii, Honolulu, 1980.

Hawaii Coastal Zone Management Program, Department of Planning and Economic Development, A Register of Government Permits Required for Development, State of Hawaii, December 1977.

The Natural Energy Laboratory of Hawaii, Policies and Procedures Manual, State of Hawaii, revised as of 2/24/82.

R.M. Towill Corporation, Revised Environmental Impact Statement for the Natural Energy Laboratory of Hawaii at Ke-ahole Point, Hawaii (Phase 1), prepared for The Research Corporation of the University of Hawaii, Honolulu, Hawaii, December 1976.

Rosendahl, Paul H., Archaeological Research Associates, Intensive Archaeological Survey and Salvage Excavations at the Natural Energy Laboratory Hawaii (NELH) Site, Ke-ahole Point, North Kona, Hawaii Island, Final Report, prepared for The Research Corporation of the University of Hawaii, Pahoa, Hawaii, January 1980. MS 2-123179.

Rosendahl, Paul H. and Patrick V. Kirch, Archaeological Reconnaissance Survey of the Ke-ahole Point Natural Energy Laboratory Site, North Kona, Hawaii Island, prepared for R.M. Towill Corporation, Honolulu-Dept. of Anthropology, Bernice P. Bishop Museum, November 1975. MS 111775 with appendix.

U.S. Department of Energy, Assistant Secretary for Environment, Office of Environmental Compliance and Overview, Environmental Assessment Seacoast Test Facility-Stage, prepared with Assistance of Argonne National Laboratory, DOE/EA-0121, November 1980.

Chapter 8

Macdonald, G.A. and Abbott, A.T., 1970, Volcanoes in Sea, University of Hawaii Press, Honolulu, 441 p.

Moore, R.B., 1979, Recent Geologic Investigations on Hualalai Volcano, Hawaii (Abstract), Am. Geophys. Union Pacific Northwest Meeting, Bend, OR.

Stearns, H.T. and Macdonald, G.A., 1946, Geology and Ground-water Resources of Hawaii, Hawaii Division of Hydrography, Bull. 9, 363 p.

Chapter 12

Jenkins, C.W., personal communication, 1983.

Turk, L.J., Evaporation of Brine: A field Study on the Bonneville Salt Flats, Utah, Water Resources Res., V6, No. 4, Pg. 1209-1215, 1970.

Schroeder, T.A., Project Ahupua'a--Solar Meteorological Field Measurements on the Island of Hawaii. 3. Trade Wind Interactions with Local Winds in South Kohala, Pub. V of Hawaii, UHMET 79-05, 1980.

Manning, R.A., Wisneski, T.P., and Clark, E.E., Conceptual Study of a Salt Gradient Pond in the Crude Oil Production Industry, Final Report, Project #82-S-3-3, Texas Energy and National Resources Advisory Council, 1983.

Chapter 13

Jenkins, C.W., personal communication, 1983.

Manning, R.A., Wisneski, T.P., and Clark, E.E., Conceptual Study of a Salt Gradient Pond in the Crude Oil Production Industry, Final Report, Project #82-S-3-3, Texas Energy and National Resources Advisory Council, 1983.

Schroeder, T.A., Project Ahupua'a--Solar Meteorological Field Measurements on the Island of Hawaii. 3. Trade Wind Interactions with Local Winds in South Kohala, Pub. V of Hawaii, UHMET 79-05, 1980.

Turk, L.J., Evaporation of Brine: A field Study on the Bonneville Salt Flats, Utah, Water Resources Res., V6, No. 4, Pg. 1209-1215, 1970.

Theoritical Efficiencies for Basic OTEC and Enhanced OTEC Power Cycles

Configuration	T - low (Deg. F)	T - high (Deg. F)	Delta T (Deg. F)	T - low (Deg. R)	T - high (Deg. R)	Carnot Efficiency
Basic OTEC	40	80	40	500	540	7%
Effluent Enhanced OTEC	40	120	80	500	580	14%
Solar Pond Enhanced OTEC	40	200	160	500	660	24%
Geothermal OTEC	40	500	460	500	960	48%
Basic Solar Ponds	80	200	120	540	660	18%
Basic Geothermal	80	500	420	540	960	44%

Notes:

Carnot Efficiency = (T,high - T,low) / T, high
= Represents the maximum theoritical thermal efficiency for a system.

Geothermal enhancement of OTEC cycle can improve theoritical efficiencies by six to seven times.

Using cold seawater for the low temperature side will only marginally improve the thermal efficiency of a basic geothermal system, however advantages do exist if the bottoming temperature can be maintained at a constant or non-seasonal affected level.

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